Contract No. and Disclaimer:

This manuscript has been authored by Savannah River Nuclear Solutions, LLC under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting this article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for United States Government purposes.

ANS EPRRSD - 13th Robotics & remote Systems for Hazardous Environments • 11th Emergency Preparedness & Response
Knoxville, TN, August 7-10, 2011, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2011)

H-Canyon Air Exhaust Tunnel Inspection Vehicle Development

Richard L. Minichan, Robert F. Fogle and Athneal D. Marzolf
Savannah River Nuclear Solutions
Savannah River National Lab
Aiken, SC 29808
richard.minichan@srnl.doe.gov; Robert.fogle@srnl.doe.gov; athneal.marzolf@srnl.doe.gov

ABSTRACT

The H-Canyon at Savannah River Site is a large concrete structure designed for chemical separation processes of radioactive material. The facility requires a large ventilation system to maintain negative pressure in process areas for radioactive contamination control and personnel protection. The ventilation exhaust is directed through a concrete tunnel under the facility which is approximately five feet wide and 8 feet tall that leads to a sand filter and stack. Acidic vapors in the exhaust have had a degrading effect on the surface of the concrete tunnels. Some areas have been inspected; however, the condition of other areas is unknown.

Experience from historical inspections with remote controlled vehicles will be discussed along with the current challenge of inspecting levels below available access points. The area of interest in the exhaust tunnel must be accessed through a 14 X 14 inch concrete plug in the floor of the hot gang valve corridor. The purpose for the inspection is to determine the condition of the inside of the air tunnel and establish if there are any structural concerns. Various landmarks, pipe hangers and exposed rebar are used as reference points for the structural engineers when evaluating the current integrity of the air tunnel.

Key Words: Crawler, Remote, Vehicle, Video, Inspection

1 INTRODUCTION

The concrete ventilation tunnels in Savannah River Site's H-Canyon have experienced some degradation over their service life. In order to determine the condition and structural integrity of the ventilation tunnels, periodic video inspections of the inside of these tunnels are performed. Since the areas of interest are radioactively contaminated, the inspections must be performed remotely. The videos are obtained using remote controlled video inspection crawlers connected through a long tether. There have been two historical deployments that will be discussed along with the current initiative which is expected to result in an inspection being performed in the summer of 2011. The approach for each task was based on experience gained in past applications using remote controlled tethered video inspection crawlers.

The current mission for the new crawler is to perform a video inspection of the crossover tunnel and the ventilation tunnel leading from the canyon building to the sand filter. A cross section of the H-Canyon facility is shown below in Figure 1. This application will require the crawler to travel further than in previous deployments potentially up to 400 feet. A sketch of the plan view of the inspection path is shown in Figure 2. Access to this tunnel is limited and must be gained through a series of vertical descents, 90 degree turns and piping interferences. Preliminary access is through a 14 inch x 14 inch concrete access plug in the floor of the Hot Gang Valve corridor which runs parallel to the process canyon. The unit will then be lowered about 10 ft to the floor below and travel approximately 80 ft before encountering a 14 ½ ft ledge which the crawler will be lowered over. Originally there was an eight inch curb at the edge of the ledge that would have to be crawled over, however, the previous inspections showed it no longer exists. Apparently erosion / corrosion inside the air tunnel eliminated the curb over the years. Once on the lower level, the goal is to inspect two to three hundred feet of tunnel going toward the sand filter.

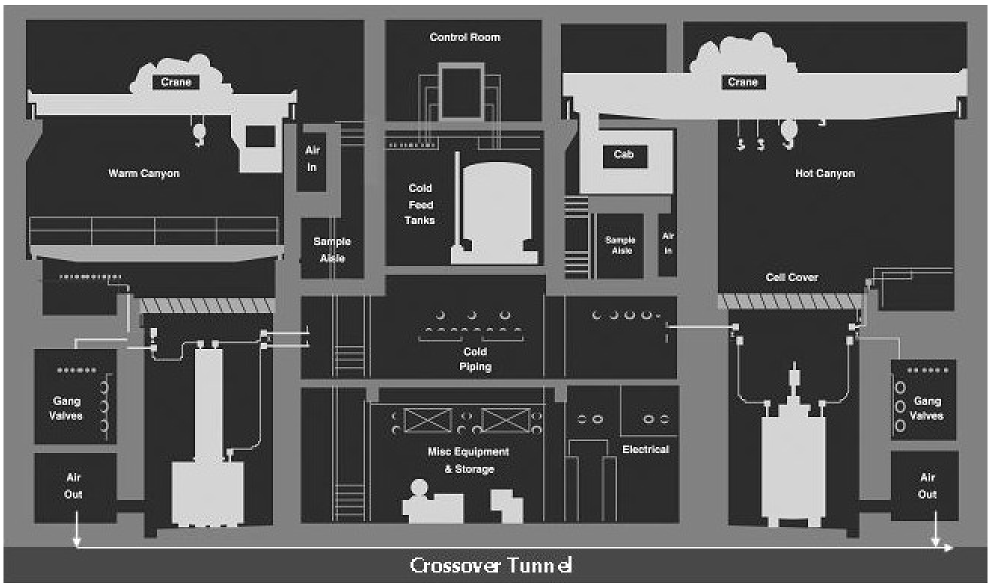

Figure 1. H-Canyon Cross Section

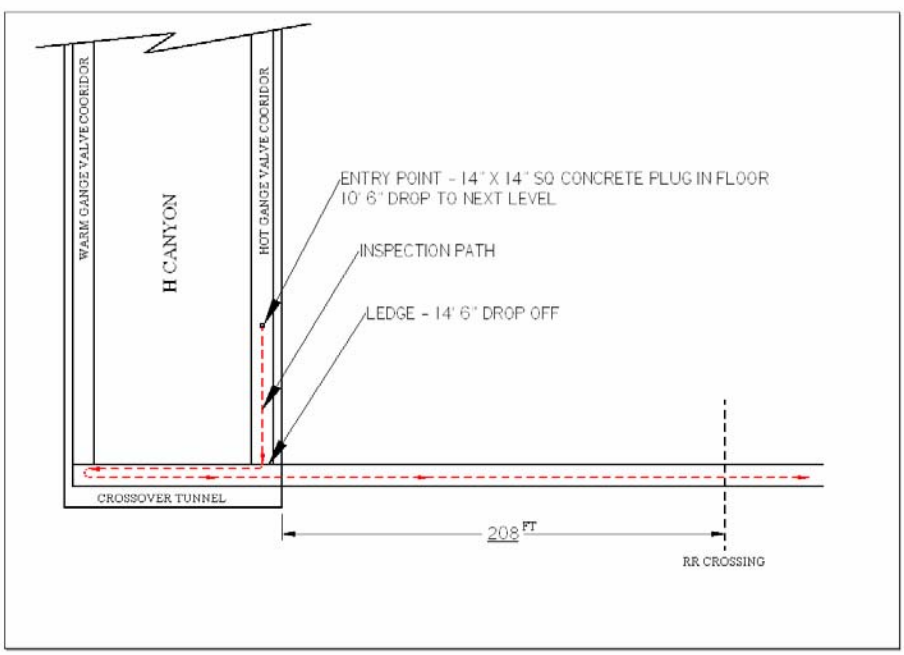

Figure 2. Plan View of Inspection Path

Video footage is used by structural engineers to determine the extent of the deterioration and if any action is warranted. In order to carry out these inspections, the SRNL Research and Development Engineering Group was asked to develop remote vehicles to deliver the required video equipment into this highly radioactively contaminated environment on three occasions. A brief description of the first deployment which was carried out by another team is included along with the details of the second vehicle and plans for the next inspection scheduled for this year are discussed in the following sections.

1.1 2003 Air Tunnel Inspection

The purpose of this assessment was to perform a structural inspection of the concrete air tunnel and to determine the source of the in-leakage between the ventilation systems of the Old HB-Line (OHBL) and H-Canyon. This crawler used a plug in the floor of the warm gang valve corridor to access the approximately 10 ft x 10 ft air tunnel. These tunnels contain additional pipe and ductwork which must be navigated. Historical degradation of the concrete tunnel due to the poor conditions inside resulted in concrete aggregate being deposited on the floor which can affect crawler traction.

A vehicle was designed for this specific purpose. Since the crawler would be abandoned in place after the inspection, a simple design was used with mostly inexpensive parts. The Inuktun Mini Tracs, the most expensive component, were used to provide motion for the crawler. These tracks were chosen because of their reliable performance in other similar applications and ability to maintain traction in challenging situations. A picture of this crawler can be seen in Figure 3 below. It has two cameras. One fixed camera pointing forward and a pan tilt zoom (PTZ) mounted on an arm that can be raised and lowered as required.

Figure 3 – 2003 H-Canyon Inspection Crawler

The original inspection path for this crawler was to lower it through the access hole to the next level and travel less than 100 feet to the retention curb at the drop off ledge. At this point, the camera on the vehicle's arm would be extended over the ledge to inspect the OHBL duct tie-in which would be about 10 feet below in the crossover tunnel. The decision was made in the middle of the project to extend the design features of this crawler by adding an extension cable to allow the crawler to negotiate the ledge to obtain a closer look at the duct tie in point. Once at the bottom of the ledge, a more detailed view of the conditions in the crossover tunnel would be possible.

The actual inspection went well and the crawler was able to successfully land at the bottom of the ledge and provide closer views and video of the duct tie in point and the crossover tunnel condition. These locations were previously unable to be seen.

1.2 2009 Air Tunnel Inspection

SRNL developed and deployed an inspection crawler similar to the unit built in 2003 for additional inspections in the H-Area hot canyon exhaust tunnel. Experience from the previous inspection and recommendations from those involved helped shape the design of the 2009 crawler. Concepts from the previous crawler along with current technology were adapted in the design for this application. The crawler used Inuktun Mini Tracs and a basic platform similar to the 2003 version. However, to reduce the size of the tether, the control system and video components were changed. Since the intent for this crawler was to travel a fairly long distance (up to 400 ft) while pulling a tether, it was decided to develop a control system designed to reduce the tether size. A dual Ethernet based system was developed and used to control the crawler platform.

Furthermore, there were two different locations in which the customer wanted to use the visual inspection vehicle. The first lies in the fan discharge exhaust tunnel under the fan house. The second is located in the exhaust tunnel under H-Canyon leading to the sand filter. In the second deployment, there were two areas of particular interest. One was under a truck well where heavy trucks cross over the exhaust tunnel in an orientation perpendicular to it. The second was where railroad cars previously crossed over the exhaust tunnel.

1.2.1 System Design

Vehicle Platform - The locomotion for the crawler was provided by commercially available Inuktun Mini Tracs. These tracks are sealed and include integral 48 volt drive motors and gearing. The tracks are very rugged and have been successfully used at SRS in numerous applications. In this application, the crawler platform supports two video cameras. One camera was mounted toward the back of the crawler that has a fixed position, pointed forward. This camera was used for driving the crawler and general viewing. The fixed camera cannot be controlled remotely; however, it has an automatic iris control to compensate for changing light conditions. A second pan, tilt and zoom (PTZ) camera is mounted on an arm that can be raised and lowered remotely (driven by a Warner electric actuator). The camera features include an 18X zoom lens, +/- 170° pan and 120° tilt. The arm provides the ability for the camera to look over ledges and be elevated for better views. There are five lights on the crawler to provide illumination for the visual inspections. One of the lights was aimed downward for viewing over ledges, while another was mounted to the arm for directional lighting. The number of lights that can be on simultaneously is limited to three due to power availability. The system has the capability to record all video signals to a dedicated computer hard drive. In addition, one video signal may be selected and recorded on a mini-DV tape which provides a better image than a VHS. A picture of the inspection crawler is shown below in Figure 4.

Figure 4 - H-Canyon Inspection Crawler

Tether - In order to keep the tether as small and light as possible a unique control technique was used on this crawler. The unit was controlled using a small PLC with communication through an Ethernet cable. The tether required only enough wire capacity for two Ethernet signals and power. Network cameras were employed to permit transmission of the video signal over a separate Ethernet connection, eliminating the need for two co-axial cables in the tether.

Control System - A General Purpose Operator Console (GPOC), developed by SRNL, provided the user interface to manipulate and control the crawler. The GPOC was designed with the ability to control a number of different vehicles. The operator console incorporates touch screen with a user-friendly GUI that allows the operator to manage the system. The GPOC uses a WAGO PLC and I/O modules to control the inspection crawler. Digital output modules control features such as lights, actuator movement (camera arm), and drive enable/disable. Digital input modules monitor the status of the left and right servo amplifiers in order to detect a fault. The servo amplifiers allow proportional control of the drive tracks through a joystick. Analog output modules drive the vehicle tracks using a joystick on the GPOC as the input. The amount of current being used by the Inuktun Tracs is displayed on the operator screen through analog input modules. The GPOC remotely controls the crawler through an Ethernet connection. A picture of the GPOC is shown below in Figure 5.

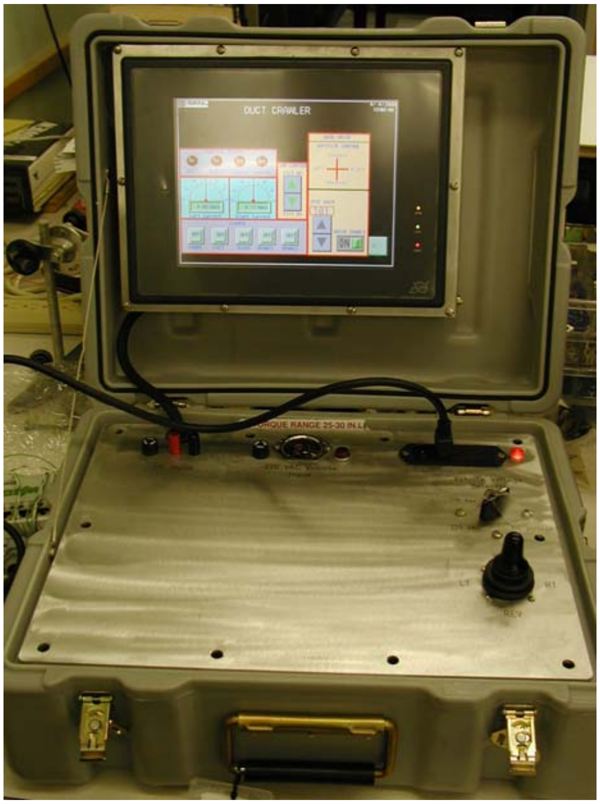

Figure 5 Universal Vehicle Controller

Vehicle Drive - The Inspection Crawler is powered by a Kepco 500 watt power unit supplying 48 V dc through two pair of 18 awg conductors in a Belden cable. The 48 V dc supply voltage powers the Inuktun drive tracks and is converted internally to 12 V dc and 24 Vdc through Astrodyne DC/DC converters. The WAGO PLC, camera arm actuator, and vehicle lights utilize the 24 V dc signal. The Axis cameras, ethernet extender, and WAGO Ethernet switch are powered by 12 V dc. The GPOC and crawler are connected with a tether that delivers power and Ethernet signals to the crawler platform. Since the crawler is intended for two applications, a tether was made for each application. The fan discharge exhaust tunnel is expected to require about 200 feet of travel so a 250 ft tether was made for this application. The canyon exhaust tunnel deployment could require as much as 400 feet of travel, therefore a 450 ft tether was made for this deployment. The additional 50 foot of tether allows the operator console to be placed in a clean location during crawler operations.

1.2.2 Testing

Tether Pull - The inspection vehicle was put through several tests to determine if it could meet the intended performance requirements. The first test was designed to confirm the vehicle’s ability to pull a 400 foot tether. The crawler was tested outside on a gravel road. The condition of the road, with loose gravel of varying size, is similar to that expected in the actual exhaust tunnels. On the gravel surface, the crawler was driven in a straight line using the 450 ft tether.

The crawler pulled the entire tether; however, the crawler tracks were occasionally observed spinning in the gravel. Although the tether length limited the travel of the crawler, the 450 feet length of the tether cable design was near the maximum that this vehicle could pull without loosing significant traction.

Ledge Decent - The second test involved driving the crawler over a ledge to determine if it could land successfully. This test was done in a straight line on two occasions. To perform this task, personnel assistance was required to control the crawler's descent, by holding and slowly extending the tether. The actual conditions in the exhaust tunnel for this evolution were not well known. Some knowledge was gained from watching a video of a previous crawler being lowered over the ledge, in the warm canyon. The test was conducted on a ledge 4-5 ft high, however, the actual ledge for this evolution was believed to be between 8-10 ft. When the crawler was slowly lowered over the ledge it landed on the tracks and continued crawling, however, the camera rubbed the ground upon landing. The camera was not damaged but the test identified the advantage of gently lowering the crawler to minimize the chance of the camera being harmed during this process. Prior to lowering the crawler over a ledge, the camera arm needed to be raised to the highest point and the PTZ camera positioned, so the camera is looking backwards. In this configuration, the crawler was in position to reduce the risk of the PTZ camera being affected by the lowering process.

Corner Tether Pull - The third test was intended to check how far the crawler could pull the tether after going around a corner. One of the locations the crawler will be used involves turning a 90 degree corner after traveling about 80-90 ft. The customer requested the crawler to travel as far as possible past this turn to maximize the area inspected. The crawler will be limited by the tether length so traveling past the turn about 300 feet is the maximum expected. The test was set up to duplicate this situation as much as possible. The tether was located about 80-90 feet from the turn and was fed from there. The crawler traveled around some 4" posts and turned 90 degrees and continued crawling. The crawler was driven 365 feet past the turn when the test was ended. The surface it was crawling on was an old worn blacktop road with some loose gravel and sand on the surface. This suggests that the crawler can pull up to about 450 feet of tether with a single 90 degree turn.

Camera Illumination - The cameras and lights were tested in a dark room to check the ability to see inside the exhaust tunnels. The crawler includes five lights that can be controlled individually. The number of lights that can be on simultaneously is limited to three due to capacity of the power supply. This test indicated that the lights on the crawler provided adequate light to view in a dark area. A light is mounted on the camera arm, which can be aimed to help direct light in specific locations. Another light is aimed down to allow the area at the bottom of the ledge to be illuminated and viewed, prior to descending. These tests were somewhat qualitative and do not exactly duplicate the tunnel conditions. The color and reflectance of the surfaces inside the tunnel may affect the light level produced by these lights.

All of these tests provided a fair representation of the field conditions. The tests demonstrate that the crawler has a high probability of performing the intended inspection tasks. However, there is always risk when executing a remote task and extra care should be given while performing the high risk steps, such as lowering the crawler over the ledge.

1.2.3 Deployment

Fan House - To deploy the crawler in the tunnel below the fan house, the control system was set up in a clean location and connected to the crawler using the 250 foot tether. The crawler was then checked to ensure all functions were operating correctly prior to entry through a hatch in the side of the stack. The crawler was driven to the door and then lifted over the ship's door threshold. Once the crawler was set inside it was driven down the slope into the tunnel for the inspection. Once the inspection was complete the tether was coiled up and placed into a plastic bag for disposal. The crawler was also placed in a plastic bag for protection until time for the canyon exhaust tunnel inspection. This deployment yielded good video footage of the condition inside the tunnel between the sand filter and stack. The concrete surfaces in this area were in surprisingly good condition according to the structural engineers. During this operation, it was discovered that the PTZ camera was not functioning properly and plans were made for repairing it prior to the next entry.

Exhaust Tunnel – The crawler was stored for several months before this evolution could be scheduled. It was discovered just prior to the inspection that the crawler was not in its expected location. It was quickly found and two entries in the maintenance area were required to repair the camera and ensure all functions were operable. The H-Canyon exhaust tunnel inspection was initiated from the hot gang valve corridor. The control system was set up and connected to the crawler using the 450 foot tether near the entry point plug. The crawler was then checked to ensure all functions were operating correctly. After the access plug was pulled by facility personnel, the crawler was lowered through a 14" square opening in the hot valve corridor floor. The lowering process required an extra rope attached to the front of the crawler. When the crawler approached the floor, the front of the vehicle was raised with the rope for upright placement on the exhaust tunnel floor. Once the crawler was securely on the floor, the rope was pulled free of the crawler. The crawler was then in a position to negotiate the exhaust tunnel for the inspection. It was driven on this level while inspecting pipe hangers and wall concrete condition. This inspection revealed concrete degradation and disconnected pipe hangers although no significant structural issues were identified. As the crawler approached the ledge everything was going well. Unfortunately, when the vehicle started driving over the ledge, all control and video signals were lost. It is believed that one of the signal wires connected at the crawler was pulled loose as the tether restrained the crawler when the descent was initiated. The lesson learned was the significance of adequate cable slack at the cable strain relief.

1.3 2011 Air Tunnel Inspection Crawler

The Savannah River National Lab was challenged by the H-Canyon customer to investigate commercial and wireless inspection technologies as potential cost effective solutions for this application. A number of potential commercial inspection devices were investigated for this purpose, resulting in several possibilities being identified. It was determined that wireless communication was too risky for this application due to the uncertainty of maintaining a signal through the thick concrete walls and unknown battery life. Ultimately, a visual inspection crawler was specified and purchased to meet the objective. A number of functional tests were performed to demonstrate the capabilities of the new unit. These include operation on gravel surfaces similar to those expected in the air tunnel and negotiating over a ledge simulating the expected path in the field. The actual inspection is expected to take place in the summer of 2011.

After some investigation, several viable commercial tethered pipe inspection crawlers were identified. Ultimately, a unit made by Power Equipment Manufacturing Inc. as seen in Figure 6 was purchased for this task. This crawler is a four wheeled crawler with one PTZ camera and lights. A power roller was added to their typical crawler design to help pull the front away from the wall when landing at the bottom of the ledge. The tether is a Kevlar reinforced five hundred foot cable with a tensile strength of around 2400 pounds. The tether has a low friction jacket to reduce the drag on the crawler as it is pulled during inspections. The tether not only protects the conductors controlling the crawler, but it also provides the support needed to control the descent of the crawler over the 14 ft, 6 in inch ledge.

Figure 6 Powervision Crawler by Power Equipment Manufacturing

Once the mobile inspection vehicle was received, a number of functional tests were performed to assure its suitability of performing the intended mission. The first test demonstrated its ability to pull the entire 500 foot tether down a gravel road with a surface similar to the one expected in the H-Canyon air tunnel. The crawler was able to pull the entire cable length with little problem. At long tethered lengths, it was observed that the crawler's ability to easily turn was compromised. In order to turn while pulling tethers greater than approximately 300 feet, the crawler must be driven backwards first to provide some slack in the cable.

The second test showed the crawler's ability to travel about 80 feet and then make a 90° turn continuing down the gravel road while pulling the full five hundred foot tether. (80 feet, 90° turn, 420 additional feet) Lastly, a scaffold was set up with plywood secured to one side. This served as a mockup to demonstrate the 14 ft, 6 in drop. The mockup also included a pile of sand at the bottom of the ledge to simulate the buildup of concrete aggregate which is a known condition from previous entries. A four inch pipe was embedded in the sand to simulate an existing drain pipe in place in the actual inspection location. Preliminary testing showed the need to make some modifications to the crawler in order to increase confidence in its ability to recover at the bottom of the ledge.

Modifications to the crawler include:

- Larger tires to increase ground clearance and improve traction.

- A modified tether attachment point to help the crawler land with its front forward at the bottom of the ledge.
- A level bubble visible at the bottom of the camera view was added to help orient the operator.
- Colored flags were added to help the operator center the camera right and left. i.e. red flag 45° right, white flag 45° left)
- Traction ridges were added to the front power roller.

With the modifications described above, the inspection crawler consistently recovered as expected after negotiating the 14 ft, 6 in drop. The modified crawler shown below in Figure 7 is now ready for the field deployment, which will take place whenever the facility can work the structural inspection into their schedule.

Figure 7 Modified Crawler at the Bottom of the Mockup Wall

2 CONCLUSIONS

The ongoing need to visually inspect inaccessible areas in the H-Canyon air tunnel has led to the development of several remote control vehicles. Obviously, there is more than one way to solve a problem as established with the variation of crawlers developed for periodic air tunnel inspections over the last 8 years. Both tracked and wheeled crawlers have demonstrated their ability to meet the mission objective either in previous field deployments or in mockup situations. The latest wheeled crawler has demonstrated its ability in a mockup situation after being modified but has not been deployed in an actual field application. Results of the field operation with the most recent crawler should be available for the conference presentation.

Using mockups is crucial to demonstrating remote controlled operations prior to deploying in radioactively contaminated areas. One can incorporate as many features into a remote tooling application as thought necessary to successfully complete its intended function but these aren't always effective. Building a mockup that closely resembles the field application and then using the remote tooling / vehicle in it, almost always reveals some issue that needs to be addressed. The cost to build a mockup, identify and resolve any issues with remote devices prior to use in a radioactively contaminated field application is typically worth the effort. Recovery or repair of a remote device in a radioactive environment can be very difficult. This project demonstrates the significance of SRNL's previous experience with similar applications and familiarity with the appropriate electromechanical components when working on remote applications such as this in meeting a customer's needs.

3 ACKNOWLEDGMENTS

A number of SRNL personnel have contributed to the effort of designing and supplying inspection crawlers for this application including: B.L. Blackman, M. Collins, R.F. Fogle, D.K. Martinez, A.D. Marzolf, C.W. Robinson & J.A. Wilson. Customer contacts in H-Area and structural engineering provided considerable guidance concerning facility conditions, desired inspection path and execution preparations. Field contacts included: G.R. Baldwin, C.J. Crawford, K.A. Dukes, R.E. Gross, M. Marshall, N.E. Mcintosh, D.L. McNicoll, L.C. Sprague, D.R. Wray.

4 REFERENCES

R.L. Minichan, M. Collins, C.L. Lindsey, "H-Area Exhaust Tunnel Remote Inspection Crawler Report," *Savannah River National Laboratory*, SRNL-RSE-2008-00026, June 19, 2008.