Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

We put science to work.™

Savannah River National Laboratory™

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

A U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY • SAVANNAH RIVER SITE • AIKEN, SC

H-Canyon Recovery Crawler

E. M. Kriikku, K. R. Hera, A. D. Marzolf, M. H. Phillips

August 2015

SRNL-STI-2015-00355, Revision 0

SRNL.DOE.GOV

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

Keywords: H-Canyon, Crawler, Recovery

Retention: Permanent

H-Canyon Recovery Crawler

E. M. Kriikku, K. R. Hera, A. D. Marzolf, M. H. Phillips

August 2015

Prepared in conjunction with work accomplished under contract number DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Savannah River National Laboratory™
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

REVIEWS AND APPROVALS

AUTHORS:

Signature on file

E. M. Kriikku, SRNL Research & Development Engineering Date

Signature on file

K. R. Hera, SRNL Research & Development Engineering Date

Signature on file

A. D. Marzolf, SRNL Research & Development Engineering Date

Signature on file

M. H. Phillips, SRNL Research & Development Engineering Date

APPROVALS:

Signature on file

B. J. Giddings, Nuclear Materials Disposition Projects Date

Signature on file

L. T. Reid, Manager SRNL Research & Development Engineering Date
Mechanical Systems and Custom Equipment Development

PREFACE OR ACKNOWLEDGEMENTS

The Recovery Crawler Project and this report required input and help from the following people.

Bill Giddings, SRNS
Lee Sims, SRNS
Jane Carter, SRNS
Jim Zelgewicz, SRNS
James Wood, SRNS
Franklin Mackie, SRNS
Kevin Tietze, SRNL
Don Varble, SRNL
Larry Powell, SRNL
George Graham, SRNL
David Silver, SRNL
David Premo, SRNL
Mike Dalmaso, SRNL
Kurt Peterson, SRNL
Rick Minichan, SRNL
Robert Holmes, SRNL
Robert Fogle, SRNL
John Gordon, SRNL
Chip Fisher, SRNL

EXECUTIVE SUMMARY

The Nuclear Material Disposition Project group asked the Savannah River National Lab (SRNL) Research and Development Engineering (R&DE) department to help procure, test, and deploy a remote crawler to recover the 2014 Inspection Crawler (IC) that tipped over in the H-Canyon Air Exhaust Tunnel. R&DE wrote a Procurement Specification for a Recovery Crawler (RC) and SRNS Procurement Department awarded the contract to Power Equipment Manufacturing Inc. (PEM). The PEM RC was based on their standard sewer inspection crawler with custom arms and forks added to the front. The arms and forks would be used to upright the 2014 Inspection Crawler.

PEM delivered the RC and associated cable reel, 2014 Inspection Crawler mockup, and manuals in late April 2015. R&DE and the team tested the crawler in May of 2015 and made modifications based on test results and Savannah River Site (SRS) requirements. R&DE delivered the RC to H-Area at the end of May.

The team deployed the RC on June 9, 10, and 11, 2015 in the H-Canyon Air Exhaust Tunnel. The RC struggled with some obstacles in the tunnel, but eventually made it to the IC. The team spent approximately five hours working to upright the IC and eventually got it on its wheels. The IC travelled approximately 20 feet and struggled to drive over debris on the air tunnel floor. Unfortunately the IC tripped over trying to pass this obstacle. The team decided to leave the IC in this location and inspect the tunnel with the RC.

The RC passed the IC and inspected the tunnel as it travelled toward H-Canyon. The team turned the RC around when it was about 20 feet from the H-Canyon crossover tunnel. From that point, the team drove the RC past the manway towards the new sand filter and stopped approximately 20 feet from the new sand filter. The team removed the RC from the tunnel, decontaminated the RC, and stored it the manway building, 294-2H.

The RC deployment confirmed the IC was not in a condition to perform useful tunnel inspections and would require significant maintenance to become inspection ready. The RC traveled approximately 660 feet in the tunnel and viewed the tunnel and ceiling wall surfaces that were not blocked by existing ducts. This deployment also documented the tunnel obstacles for future inspections. Overall, the RC deployment was a success.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CAEX...............Canyon Air Exhaust
DOE.................Department of Energy
dpm..................Disintegrations per Minute
eHAP................Electronic Hazard Assessment Program
EM...................Environmental Management
IC.....................Inspection Crawler
JHA..................Job Hazard Assessment
mrem................milli-Roentgen Equivalent Man
PEM.................Power Equipment Manufacturing Inc.
RC....................Recovery Crawler
R&DE..............Research & Development Engineering
SRNL...............Savannah River National Laboratory
SRNS...............Savannah River Nuclear Solutions
SRS..................Savannah River Site

1.0 Introduction

The H-Canyon Air Exhaust Tunnel (CAEX) connects the canyon, building 221-H, to the sand filter, building 294-1H. The CAEX tunnel was built with the canyon in the 1950s and SRNS is required to inspect the CAEX tunnel on a periodic basis for structural integrity. In 2014, the IC was deployed in the CAEX tunnel to visually inspect the tunnel walls. Unfortunately, the 2014 IC tipped over about 330 feet from the entry port located near the old sand filter, building 294-H.

The Nuclear Materials Disposition Projects requested SRNL R&DE to help procure, test, and deploy a Recovery Crawler with a Technical Assistance Request [1]. R&DE wrote Procurement Specification M-SPP-H-00527 [2] and a Sole Source Justification for PEM to provide the 2015 Recovery Crawler. PEM provided the 2014 Inspection Crawler and the team felt their 2014 Inspection Crawler knowledge was critical to design a successful 2015 Recovery Crawler. SRNS placed Purchase Order SRNS-00189973 with PEM on December 17, 2014.

PEM delivered the 2015 RC on April 30, 2015. R&DE tested the RC during the month of May, and the team deployed the RC on June 9, 10, and 11 in 2015. This report documents the 2015 RC procurement, testing, and deployment.

2.0 Project Goals

The following lists the Recovery Crawler project goals.

1. Recover 2014 IC for future inspections.
2. If the 2014 IC does not function, move the 2014 IC from the pathway to allow future inspections.
3. Inspect CAEX tunnel as feasible. The first option was to use the 2014 IC and the second option was the 2015 RC.
4. Decontaminate and remove the 2015 RC from the CAEX tunnel.
5. Decontaminate and remove the 2014 IC from the CAEX tunnel.

The Project Team developed a decision tree to help manage the project during the deployment, Appendix A shows the Decision Tree. Since there were several scenarios that could emerge during deployment, (for example, will the 2014 IC function?) the decision tree allowed the team members to plan for these cases.

Figure 1 shows the 2014 Inspection Crawler during testing and Figure 2 shows the 2015 RC.

Figure 1 - 2014 Inspection Crawler

Figure 2 - 2015 Recovery Crawler

3.0 Procurement

R&DE wrote Procurement Specification M-SPP-H-00527 Revision 0 [2] with help from H-Canyon Engineering, Operations, and the RC Project Manager. The specification was issued on 9/11/2014 and is available from Savannah River Nuclear Solutions (SRNS) Document Control. The specification includes the RC performance and design requirements which include: enter the CAEX tunnel through the 30 inch diameter manway, travel approximately 330 feet to the 2014 IC, upright the Inspection Crawler, use a pan/tilt/zoom camera, and be water proof.

The team wrote a Sole Source Justification for PEM to provide the RC. The Sole Source is included in the Purchase Requisition [3] and Appendix B shows the Sole Source Justification. The primary reasons for selecting PEM were: 1) lower cost compared to other companies contacted, 2) PEM provided the 2014 IC and owned the proprietary information needed to recovery the 2014 IC without damaging it, and 3) SRNS required the 2014 IC and 2015 RC have interchangeable cables and PEM owned the detailed wiring information need to complete this requirement.

R&DE issued the RC specification revision 1 on 9/21/2014 to clarify several requirements based on PEM questions and remove the second camera requirements. PEM stated the second camera would require a new cable that would increase cost and push the delivery time out several weeks.

R&DE issued the RC specification revision 2 on 12/17/2014 and this added the overall RC length requirement of 58 inches. The team didn’t have this requirement until the building, manway, and hoist design were complete.

SRNS awarded a contract [4] to PEM for the H-Canyon Recovery Crawler on 12/17/2014. SRNS issued a revision on 1/6/2015 to include the latest specification revision.

The RC specification required the supplier to submit a conceptual design and for SRNS to review and approve the design before fabrication begins. On 1/5/15, PEM submitted a Recovery Crawler Conceptual Design sketch, see Appendix C. SRNS sent PEM several questions about the sketch and PEM provided responses to each question. SRNS team members reviewed the PEM sketch and the PEM responses and approved the PEM conceptual design. R&DE issued a report [5] to document the PEM conceptual design, SRNS questions, PEM responses, and the SRNS design approval.

The RC specification required the supplier to demonstrate all the requirements to SRNS personnel. On April 16, 2015, Dale Marzolf from R&DE and Bill Giddings from H Canyon went to PEM in Pensacola, Florida to observe the RC demonstration. Dale and Bill brought a checklist based on the specification to record the demonstration results. Dale Marzolf documented the results in a report [6] and in summary, the PEM RC passed the acceptance test. There were a few items that were not completed for various reasons and the report includes comments describing the reasons.

PEM delivered the RC and associated items on 4/30/2015. Appendix D shows the Bill of Laden, a list of deliverables, and a small picture of each deliverable. The RC specification required PEM to deliver at the minimum electrical schematics, Operation Manual, and Maintenance Manual. PEM included all three items in one document [7]. Figure 3 shows the RC, mockup IC, and cable reel when they first arrived at SRNL.

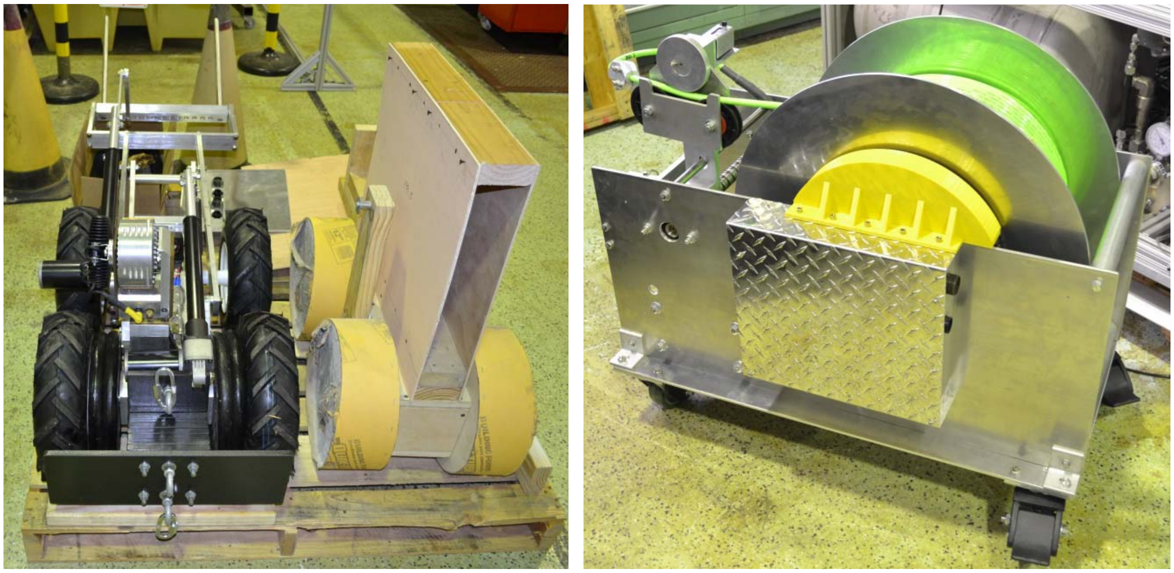


Figure 3 - Recovery Crawler, Mockup Inspection Crawler, and Cable Reel

4.0 Recovery Crawler Details

PEM designed the RC to drive to the IC and upright the IC. The RC had two drive motors, one for the left wheel and one for right wheels. The RC has two actuators, one to raise and lower the arms and one to raise and lower the forks. The drive motors and actuator motors have variable speed controls to help control driving and actuator motions. The RC has one pan/tilt/zoom camera and a light mounted next to the camera that moved with camera pan and tilt motions. PEM installed approximately 70 pounds of counter weights on the rear axles and approximately 25 pounds on the back of the RC to prevent it from tipping forward while lifting the 180 pound IC. The RC weighs approximately 320 pounds. PEM included an inclinometer that shows the RC tilt and roll and a bracket to hold dosimeters. The RC camera could see the inclinometer and dosimeters and Figure 18 shows these items.

SRS Rigging modified the RC lifting bail to meet site rigging requirements and to be compatible with the IC lifting bail. R&DE added a cable swing arm to help keep the RC tether away from the wheels when the RC moved backwards. Figure 4 shows the RC and several of these features.

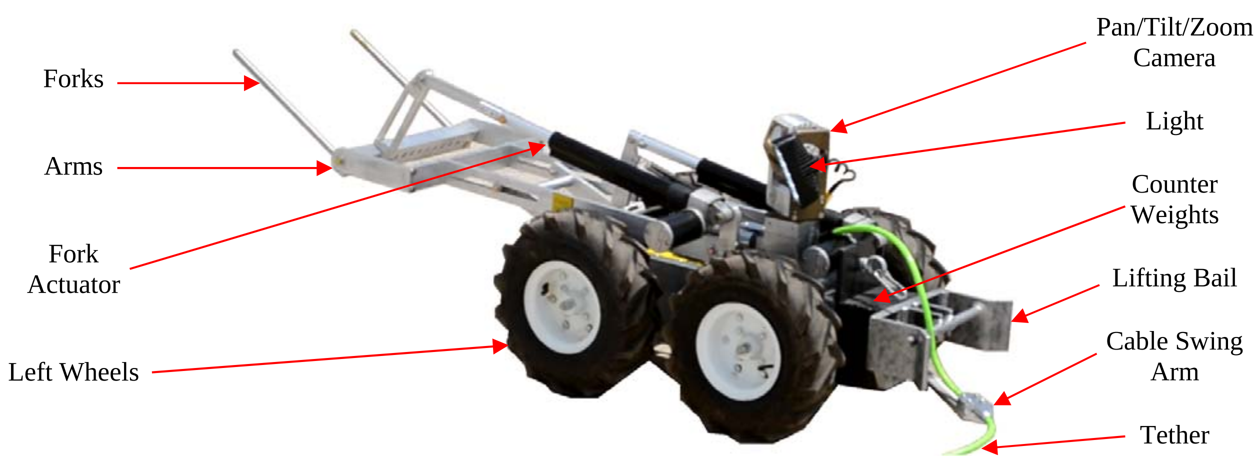


Figure 4 - Recovery Crawler Details

5.0 Preparations

R&DE issued several documents before using the Recovery Crawler, Cable Reel, Spray Wand, Crew Trailers, and Power Box. Table 1 lists the documents and a description.

Table 1 - Recovery Crawler Pre-Deployment Documents

No.	Document Title - Number	Description / Comments
1	Recovery Crawler electronic Hazard Assessment Process (eHAP) [8]	This is lists all the potential hazards associated with using the RC and the controls used to mitigate each hazard. Several Subject Matter Experts review the eHAP to ensure all hazards are mitigated. SRNL uses eHAPS and they are similar to an SRS Automated Hazard Assessment.
2	Recovery Crawler Testing Job Hazard Analysis (JHA) [9]	This lists the activities associated with operating the RC, the hazard, and preventative controls.
3	Recovery Crawler Final Acceptance Inspection [10]	This is the new equipment safety inspection. Four items were found during the inspection and all were corrected before using the RC.
4	Recovery Crawler Electrical Evaluation [11]	This is the assessment of unlisted or modified electrical equipment for use at SRS. See Engineering Guide 16980-G in Manual WSRC-IM-95-58.
5	Spray Wand Final Acceptance Inspection [12]	This is the new equipment safety inspection. No items were found during the inspection.
6	Crew Trailers and Power Box Final Acceptance Inspection [13]	This is the new or modified equipment safety inspection. Two items were found during the inspection and all were corrected before using the trailers and power box.
7	Power Box Electrical Evaluation [14]	This is the assessment of unlisted or modified electrical equipment for use at SRS. See Engineering Guide 16980-G in Manual WSRC-IM-95-58.
8	R&D Directions – H-Canyon Recovery Crawler and Spray Wand Testing [15]	This is the direction for using the RC and Spray Wand. It lists the unique hazards associated with the RC and Spray Wand and the hazard controls.
9	Recovery Crawler and Cable Reel Work Instructions [16]	This document provides instructions for setting up, operating, and shutting down the Recovery Crawler and Cable Reel.
10	H-Canyon Recovery Crawler Test Plan [17]	This outlines the planned tests for the Recovery Crawler and Spray Wand.
11	A Review of the H-Canyon Air Exhaust Tunnel Recovery Crawler [18]	This was an independent RC review by two former SRNL Robotics employees. The report includes several observations and recommendations. R&DE implemented most of the recommendations, for example, extensive testing.

6.0 Testing

R&DE issued the Recovery Crawler Test Plan [19] and this included the Test Lead, Test Dates, Test Description, Work Groups involved, Responsibilities, Location, Equipment needed, and Test Steps. Table 2 lists the test step description from the Test Plan, a Pass/Fail result, and comments from each test.

Table 2 - Test Plan Steps

No.	Test Description	Pass/ Fail	Comments
1	Ensure the Recovery Crawler cables are connected and all functions are working properly.	Pass	The RC cables and bulkhead are connected and the RC is working properly.
2	Drive the Recovery Crawler away from the control station on a dirt/sand/mud surface until 700 feet of tether are off the cable reel. The goal is to get debris on the cable to simulate pulling the entire cable in the air tunnel. Turn the Recovery Crawler around and return to the control station. Use the cable reel to retract the tether as the crawler gets closer to the control station. Verify the cable reel counter is working properly and recording actual length.	Pass	Drove the RC on concrete, asphalt, gravel, and grass. Route included a 90 degree turn around a wooden cable reel, see Figure 5. Couldn't find an available road with dirt and mud. Crawler may be going slightly slower at full cable length. Cable counter was about 15 feet higher that the marking on the cable with all 700 feet out. The cable counter was about 5 feet higher than the markings on the cable when the cable was retracted.
3	Place the Recovery Crawler on the raised platform in the normal operating position (on its wheels). Attach the hoist to the Recovery Crawler's lift point. Use the hoist to raise the crawler into the vertical position.	Pass	Rigging made a new back plate for lifting the RC, see Figure 6. Rigging used the hoist to raise the crawler from its wheels to the vertical position.
4	Position the portable blowers below the platform and turn them on. Use the hoist to lower the Recovery crawler through the Manway. Use the hoist and crawler attachments to land the crawler on its wheels below the platform.	Pass	1) The team decided the portable blowers did not add much value based on the previous tunnel entry, so they were not used. 2) Rigging used the hoist short chain hook to lower the RC through the manway, see Figure 7.
5	Release the Recovery Crawler from the hoist and drive the crawler away. Turn the portable blowers off.	Pass	Rigging released the hoist from the RC and the RC was driven a short distance. The scaffolding prevented the RC from moving any real distance. The portable blowers were not used, see step 4.
6	Place the Inspection Crawler (IC) mockup on its side with the camera under a simulated 36" diameter pipe. Drive the Recovery Crawler to the Inspection Crawler. Lift the Inspection Crawler camera support structure without touching the simulated pipe and hold it off the ground for 30 seconds (IC wheels can remain on the ground). Repeat this test with the Inspection Crawler in various configurations under the simulated pipe. The first lifting option is to place the Recover Crawler forks under the Inspection Crawler. Other methods can be tested during this step.	Pass	The RC forks were placed under the IC trunnion support and the RC was able to lift the IC mockup so the camera assembly was off the ground for 30 seconds. The IC wheels remained on the ground during the lift. The test was successfully repeated with the IC mockup in several orientations. Figure 8 shows the RC, IC, simulated 36" pipe, and simulated tunnel wall. The RC forks were placed under the tires and under the IC body, but these methods were not able to lift the IC camera assembly.
7	Use the Recovery Crawler's attachments to upright the Inspection Crawler from its side to its wheels. Other methods can be tested during this step.	Pass	The RC successfully up righted the IC from several different starting positions. Eight R&DE personnel practiced and were able to upright the IC. Figure 9 shows the RC up righting the IC with the forks under the trunnion support.

No.	Test Description	Pass/ Fail	Comments
8	Use the Recovery Crawler's attachments to push the Inspection Crawler mockup in a sand and gravel mixture. This simulates moving the Inspection Crawler if it can't be driven. This test can be repeated with the Inspection Crawler in various orientations or in various materials.	Pass	The RC pushed the IC in the dirt, sand, and gravel mixture. The forks were up all the way and the fork crossbar pushed on the IC wheels. When the IC wheels are close to the 36" diameter pipe, the RC could only push the IC further under the pipe. There was no good way to pull the IC. R&DE added a 4" threaded rod to the fork cross bar. The RC was able to use this rod as a crewed hook and pull the IC in the dirt and gravel.
9	Place the Inspection Crawler mockup on its side. Drive the Recovery Crawler to the Inspection Crawler. Lift the Inspection Crawler with the attachments and attempt to drive the Recovery Crawler. This will determine if this is a viable option for recovering the Inspection Crawler. Other methods can be tested during this step.	Fail	The RC cannot get the IC mockup off the ground. PEM changed their bucket and chain concept to the fork concept for this reason. The RC can only push and pull the IC for a few feet. After a few feet, the dirt and gravel builds up in front of the IC and eventually the RC can't move it farther.
10	Drive the Recovery Crawler under the Manway. Use the hoist on the platform to lift the Recovery Crawler off the ground.	Pass	Rigging used the hoist and long yoke to grab and lift the RC through the manway.
11	Ensure the Spray Wand hoses and cables are connected and all functions are working properly. Add clay, mud, sand or other debris to the Recovery Crawler wheels, and frame as needed. The Spray Wand will attempt to remove this debris.	N/A	The Spray Wand was assembled and demonstrated by spraying water in the air. The H Area people wanted more water pressure, so R&DE ordered and demonstrated a new water pump with the Spray Wand. The H Area Operations people placed the Recovery Crawler and Spray Wand below the manway to ensure the Spray Wand had room to be effective. Figure 10 shows the Spray Wand and RC below the manway.
12	Use the Spray Wand to clean the Recovery Crawler while it is suspended under the Manway. Use the hoist to raise and lower the crawler during cleaning. Rotate the crawler and move the Spray Wand to simulate cleaning all crawler surfaces.	N/A	The H-Area Operations people decided The actions in step 11 were enough and water testing was not needed.
13	Remove the Spray Wand and use the hoist to raise the Recovery Crawler through the Manway. Use the hoist to place the crawler on the platform deck on its wheels.	Pass	Rigging demonstrated the transition from the long lifting bail to the short chain and removing the RC from the manway and placing it on the scaffolding. Figure 11 show the RC in the manway on the long lifting bail.

No.	**Test Description**	**Pass/ Fail**	**Comments**
14	Drive the Recovery Crawler to the video test area and record Recovery Crawler video. Include reading the EPD on the Recovery Crawler with the camera. Playback recorded video and determine if quality is acceptable. Ensure the EPD reading is visible.	Pass	Large pictures from a past pole camera inspection were printed and taped to the inner wall of an empty sea land container. The RC was placed in the container, the doors were shut, and openings were covered leaving the RC in a dark container. The RC camera and light were used to look at the these pictures and the images were recorded. The team felt the recorded images were not great, but they were acceptable.
15	Record any observations. If other tests are needed, document the test conditions and the results.	Pass	Due to time limitations, observations were discussed with team members and any problems were corrected immediately.
16	Record any action items that came up during the testing and assign a responsible person to each item.	Pass	Due to time limitations, action items were discussed with team members and corrected almost immediately.

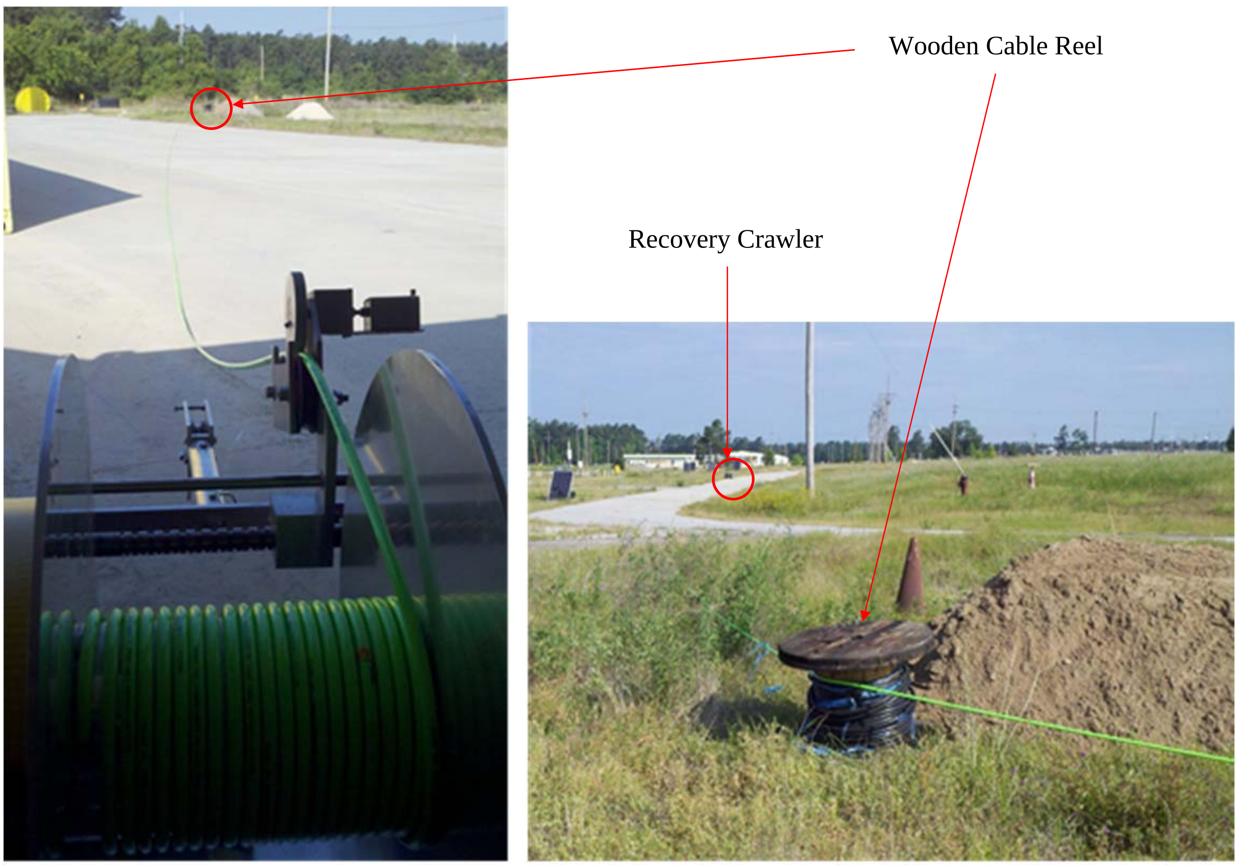


Figure 5 – Recovery Crawler Full Tether Test

Figure 6 - Recovery Crawler Back Plate and Cable Swing Arm

Figure 7 - Recover Crawler Being Lowered Through the Manway

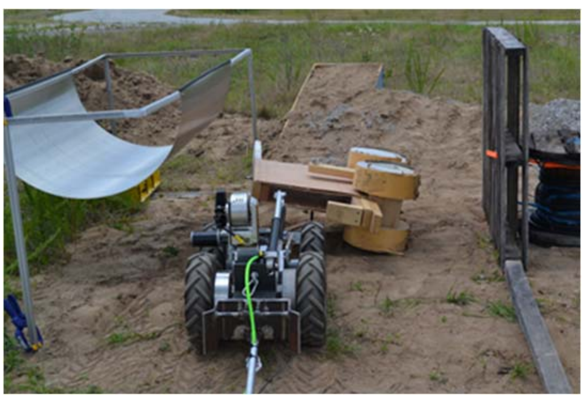


Figure 8 - Recovery Crawler Lifting Mockup Inspection Crawler

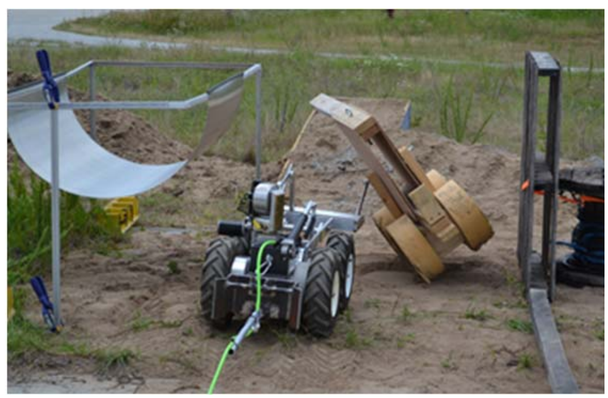


Figure 9 - Recovery Crawler Up Righting the Mockup Inspection Crawler

Figure 10 - Recovery Crawler and Spray Wand Below the Manway

Figure 11 - Recovery Crawler in Manway on Long Lifting Bail

R&DE determined that the RC deployment would require four operators, one to operate the IC, one to operate the RC, one to operate both cable reels, and one to operate the DVR/cameras. Since the deployment date was subject to change, R&DE trained eight people on the RC, RC cable reel, and DVR. The IC and IC cable were in H-Area and not available for testing or training.

During testing, the Project Manager asked R&DE to purchase two Never Wet products, one for leather and rubber and the other for hard materials like metal and concrete. This product is sprayed on materials and prevents liquids from absorbing and clinging the base material. R&DE ordered both products and got the MSDSs in the SRS system [20, 21]. SRNL could not complete the chemical hazard review before the testing completed, so both products were delivered to the H-Area customer and not tested with the RC.

7.0 Modifications

Due to limited time for testing, the team did not want to make major changes to the RC system. The following changes were made during the testing period.

1. R&DE added covers to the exposed cable reel rotating parts.
2. R&DE added a base plate and casters to the cable reel.
3. R&DE raised the cable reel arm slightly to clear the manway.
4. Rigging designed and installed a new lifting bail and guide system to meet SRS lifting requirements and be compatible with the lifting bails planned for this project. Figure 6 shows the lifting bail.
5. R&DE removed the four delivered weights on the rear axle and installed two smaller diameter weights. This removed the gap between the weights that would hold contamination and the smaller diameter weights would drag less in the debris. Figure 6 shows the two weights on the rear axle.
6. R&DE designed and installed a swing arm to keep the tether away from the rear wheels. Figure 6 shows the swing arm.

8.0 Deployment

The team deployed the Recover Crawler from building 294-2H, see Figure 12. The building provided containment when the manway cover was off and the Contamination Area to Radiological Buffer Area transition. The portable tent outside the building provided a cool down location and covered the breathing air halo and ice barrel. The crew trailer, observation trailer, generators, water tank, and Spray Wand water pump were located up the hill to the North of 294-2H, see Figure 13. The portable breathing air compressors were located to the East of the water tank, just out of frame in Figure 13.

Figure 12 - Building 294-2H

Figure 13 - Crew Trailers, Generators, Water Tank

Figure 14 shows inside the 294-2H building before the team opened the manway. Items shown include: the RC, both IC and RC cable reels (IC reel is empty, cable in tunnel), video monitor on the left wall, and the bulkhead plate on the back wall. Figure 15 shows the four SRNL control positions inside the control trailer. From left to right, the IC controls, cable reel controls and 294-2H camera controls, RC controls, and Digital Video Recorder controls. The second crew trailer, or observation trailer, provided a cool down area for the workers and large video monitor that showed all active camera views for visitors.

Figure 14 - Inside 294-2H

Figure 15 - Inside Control Trailer

To begin the deployment, the team opened the manway and removed the IC cable that was hanging from the manway cover plate. The manway is the port from 294-2H to the CAEX tunnel. The team inspected the IC cable, attached it to the IC cable reel, and tested the IC. The IC cameras came on and the driver turned the wheels slightly. The next step was to insert the RC in the tunnel.

Figure 16 shows the RC entering the manway. Due to the low ceiling in the 294-2H, the RC forks had to be raised to allow the crawler to pass over the manway edge, but the forks had to be positioned straight down in order to fit the RC through the 30 inch inner diameter manway. Once through the manway, the team raised the RC forks to help transition the RC from a vertical orientation to on its wheels. The dose rate into the manway was 2.0 mrem/hour beta and 0.6 mrem/hour gamma.

Figure 16 - Recovery Crawler Entering Manway

Once the RC reached the CAEX tunnel floor and operated properly, the team installed a temporary manway cover. This cover reduced the air flow through the manway and a slot in the cover allowed the IC and RC cables to pass through. The team drove the RC West towards the IC and soon encountered a large puddle. Figure 17 shows the RC approaching the puddle and Figure 18 shows the RC in the puddle. The IC encountered this puddle, so the team planned to traverse the puddle. The team drove the RC into the puddle and had trouble exiting the puddle on the left side of the column in Figure 17. After several attempts, the RC got stuck. Team members had to reenter 294-2H and pull the RC out of the mud by pulling on the tether. The RC tether is rated for 2,500 pounds of pulling force, so pulling on the tether was the backup plan if the RC got stuck. After the team pulled the RC from the puddle, the team decided to exit the puddle in a different location, on the right side of the column shown in Figure 17. After a few attempts, this new route worked and the RC continued West towards the IC.

Figure 17 - RC Approaching Puddle

Figure 18 - RC in Puddle, Approx. 13" Deep

After passing the puddle, the RC came to a concrete sample coupon that was placed in the tunnel in 2012. The RC stopped before, next to, and after the coupon to zoom in and get a good view. Figure 19 shows the entire sample and Figure 20 shows a close up view.

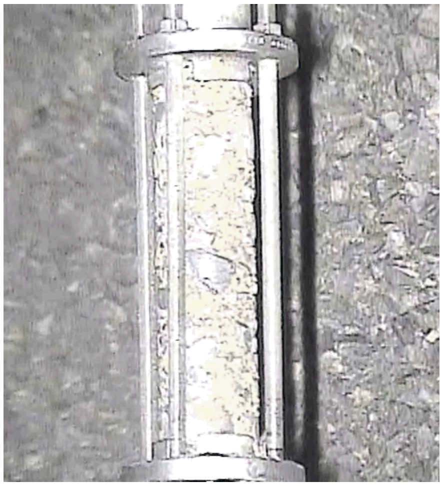


Figure 19 - Concrete Coupon

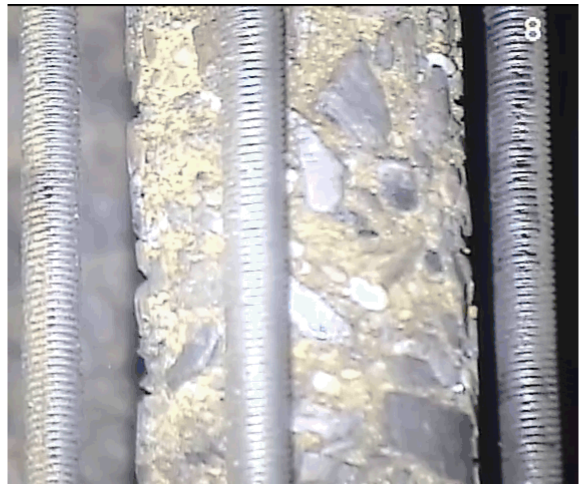


Figure 20 - Concrete Coupon Close Up

The RC encountered a pipe hanger lying across the tunnel, see Figure 21. The vertical pipe in Figure 21 previously housed a probe and the pipe hanger is obscured by the debris on the ground. It took several attempts to cross the pipe hanger. The RC front wheels would get over the hanger, but all the RC wheels would spin when the back wheels got to the hanger. The ruts shown in Figure 21 were made from attempts to drive over the hanger. The team tried to move the pipe hanger with the RC forks, but these attempts were not successful. The RC passed the hanger by driving close to the North wall (right side, away from the probe).

The RC encountered several expansion joint covers, these are rectangular sheet metal pieces lying on the floor near the expansion joints. Figure 22 shows some typical expansion joint covers. The RC did not have any issues crossing over these covers.

Figure 21 - Pipe Hanger

Figure 22 - Typical Expansion Joint Covers

Figure 23 shows typical wheel ruts in the debris on the floor. Other challenges the RC faced included: 25 to 30 miles per hour wind, acid vapors, and beta and gamma radiation. Figure 24 shows the IC laying on its left side in the CAEX tunnel.

The plan to upright the IC included sliding the RC forks under the IC, engaging the IC left side lifting bail with the RC fork, raising the IC scissors and camera above the debris, lowering the IC scissors, retracting the camera slide, and finally rolling the IC to its wheels. The team tried to engage the IC lifting bail, but these efforts were not successful. The team used the RC to move the IC in attempt to get the forks to the lifting bail, but again these efforts were not successful. Later analysis theorized that the IC scissors latch added after the IC was delivered to SRS, interfered with the RC forks/arms and preventing the forks from reaching the lifting bail.

Figure 23 – Typical Wheel Ruts

Figure 24 - IC on its Left Side

After the team saw the IC scissors components and saw no hint of scissor movement when the scissor actuator was driven, the team decided to engage the RC forks on the IC scissor components to upright the IC. Figure 25 shows the IC being lifted up and Figure 26 shows the IC on its wheels. The up righting process required a coordinated effort between the IC and RC drivers. The IC driver was driving the wheels in reverse and the RC driver was lifting the forks and driving forward. The team developed this method during the deployment with several trial and error iterations. The team spent about 5 hours working to get the IC on its wheels.

Figure 26 also shows the IC on its wheels, but the camera is lodged under the 36 inch diameter pipe. The team used the RC forks to push the scissors down, but the scissors only moved down a few inches. The IC driver tried to back the IC away from the pipe, but the IC would not move. The IC scissors and camera slide did not move either. The RC driver used the forks to lift the IC rear wheels in an attempt to free the IC camera, but this was not successful. The IC driver tried to skid turn the IC away from the pipe and this freed the IC from the pipe. Since the IC tether was all around the IC, the team drove the IC further into the tunnel to clear the cable.

Figure 25 – RC Lifting IC

Figure 26 - IC on its Wheels

The team reviewed the IC functionality and noted the scissors lift didn't work, the camera slide didn't work, and the camera images were blurry. The team decided that the IC was not going to perform valuable tunnel inspections in this condition, so the plan was to return the IC to the manway. The IC travelled approximately 20 feet in reverse towards the manway and had trouble getting traction on an expansion joint cover. Figure 27 shows the IC struggling on the expansion joint cover. While trying to get over the expansion joint cover, the cover sank suddenly and the IC fell on its left side under the large diameter pipe. Figure 28 shows the IC on its side after this fall.

Figure 27 - IC on Expansion Joint Cover

Figure 28 - IC on its Left Side

Once the IC fell, the team decided to leave the IC in its current location based on the following factors;

1. The IC is very unstable in its current configuration, scissors partially up and camera slide out, so driving to the manway would be challenging.
2. The inspection camera produced blurry images.
3. Removing the IC from the CAEX tunnel would be challenging. The IC will not fit through the 30 inch diameter manway with the scissors partially up.
4. The IC will need a lot of repairs to be a viable inspection device in the future.
5. The RC and future crawlers have room to pass the IC in its current location.

The team decided to inspect the remaining tunnel with the RC. After passing the IC, the team stopped the RC approximately every 20 feet to video the walls and ceiling. This video record will be used by the Structural Analysis Group in their tunnel structural analysis. As the RC progressed down the CAEX tunnel, it passed the 2011 Crawler, see Figure 29. This crawler entered the tunnel from the Hot Canyon Exhaust Tunnel and traveled East until it could not continue. As the RC approached the H-Canyon Crossover Tunnel, the 2003 and 2009 crawlers came into view. Figure 30 shows these two crawlers and a small puddle before the crawlers. This puddle covers a sump pit and the team felt the RC was likely to become stuck in this pit. Due to this risk, the team decided to turn the RC around at this point and return to the manway.

While turning the RC around, the RC got stuck in the gravel and debris. The RC driver used the forks and arms to push the RC off the obstruction and after a few attempts, the RC was free and able to complete the turn. The drive back to the manway progressed well; the RC passed the IC without issue and passed the pipe hanger on the first try.

Figure 29 - RC Passing 2011 Crawler

Figure 30 - RC Approaching 2003 & 2009 Crawlers

The RC had trouble getting over the expansion joint covers near the pond. Figure 31 shows this expansion joint and note the RC had no problem crossing this joint on the way into the tunnel. The front wheels would get over the joint, but the back wheel would get stuck on the joint and the RC front end would raise up. The team decided to turn the RC around and back over the joint. This technique was successful during testing. While turning the RC around, the tether got tangled in the RC axles. The team felt pulling on the cable at this point wouldn't help, so the RC driver continued the turn and drove over the joint in reverse on the first try. The RC approached the pond in reverse and stopped at the top of the hill. At this point, water was observed dripping from the ceiling near the support column and falling into the pond. Figure 32 shows the support column top and the area where the team observed water dripping.

Figure 31 - Expansion Joint

Figure 32 - Support Column and Tunnel Ceiling

The team decided to drive the RC backwards through the puddle so the option to pull the cable could be used if needed. While the operators were dressing out the RC drivers used the arms, forks, and a series of back and forth moves to untangle the RC tether. The operators pulled the entire cable back to the manway and when the tether was taught, the RC entered the puddle backwards. After multiple attempts and with help from the cable being pulled, the RC crossed the puddle.

The RC driver turned the RC around and drove to the manway. Figure 33 shows the green RC cable hanging from the manway and an air inlet into the old sand filter, building 294-H. The RC drove approximately 150 feet past the manway to the new sand filter, building 294-1H. At this location, there is a steep drop and the team felt the RC would not get back up over the drop. Figure 34 shows the view from the location where the RC stopped.

Figure 33 - RC Passing the Manway

Figure 34 - RC Stopped Between Sand Filters

The RC drove backwards to the manway while the operators pulled the tether up into the manway. When the RC was below the manway, the RC driver raised arms and forks, the Riggers lowered the lifting bail, grabbed the RC, and raised it off the tunnel floor. Figure 35 shows the lifting bail grabbing the RC. While the RC was suspended in the Tunnel, the operators used the Spray Wand to decontaminate the RC. Figure 36 shows the spray wand, the two lower lights, lower camera, and red water hose. Not shown are the upper camera and the joints that allow the Spray Wand to be collapsed for storage and insertion with a low ceiling.

Figure 35 - Lifting Bail Grabbing the RC

Figure 36 - Spray Wand

Figure 37 shows a view from the upper Spray Wand camera looking down through the manway. The chain holding the lifting bail/RC and the water spray can be seen hitting the left rear wheel. Figure 38 shows a view from the RC camera. The water spray is being directed at the right front wheel. Once the RC appeared to be clean, the Riggers raised the RC up into the manway and allowed it to dry. Since the manway cover plate was off, air passed through the manway and dried the RC in approximately twenty minutes.

Figure 37 – Spray Wand Decontaminating the RC

Figure 38 - Spray Wand Water Hitting the RC Wheel

As the Riggers raised the RC from the manway, Radiation Control personnel took several smears to ensure safe dose rates. The RC dose rates after the decontamination were 6,000 dpm/100 cm2 alpha, 10,000 dpm/100 cm2 beta/gamma. While the RC was hanging in 294-2H, personnel lowered the first bag down over the RC. This bag had been staged on the hoist before the deployment began. Figure 39 shows the first bag being lowered onto the RC while it hangs over the manway.

Operators cut and disposed as waste the RC tether that went into the tunnel. Both tether ends with connectors were saved in case wire color to pin numbers had to be verified in the future. Operators placed the bagged RC into a custom design storage bag. Figure 40 shows the RC in this custom bag. The RC was left in the building 294-2H until it is needed in the future.

Figure 39 - First RC Bag Being Installed

Figure 40 - RC in Custom Storage Bag

Appendix E shows all the H-Canyon Air Exhaust Tunnel inspection routes including the 2015 Recovery Crawler route. Note that the 2003, 2009, and 2011 crawlers entered from H-Canyon while the 2014 and 2015 crawlers entered from the manway in building 294-2H.

9.0 Conclusions

The following are conclusions from the 2015 Recovery Crawler project:

1. The IC was not in a condition to complete a tunnel inspection.
2. The IC would require significant maintenance to get into an inspection ready condition.
3. The IC is in position to allow future crawlers to pass by.
4. The RC traveled 660 feet in the tunnel and captured video of tunnel ceiling and wall surfaces.

5. The RC captured video of ceiling and wall surfaces in approximately 150 feet of uninspected tunnel.
6. This deployment documented tunnel obstacles for future inspections.

10.0 Path Forward

The following items are planned as follow on activities to the 2015 Recovery Crawler project:

1. Structural Mechanics will review and analyze the RC video and determine tunnel structural integrity.
2. Lessons learned will be documented and used as reference for future tunnel crawler projects. The primary RC lessons learned are that the inspection camera needs to have megapixel resolution (the RC has a standard definition camera).
3. Future crawlers need to be able to handle the tunnel obstacles or the obstacles need to be removed.
4. Determine the next tunnel mission and evaluate if the RC, a modified RC, or new inspection vehicle is the best option for this mission.

11.0 References

R&DE Job Folder 23520 entitled, "H-Canyon Recovery Crawler" contains each reference. Documents with numbers that begin with, "SRNL-L4500-…" are also stored the SRNL Correspondence Log.

[1] SRS Technical Assistance Request, "H-Area Recovery and Inspection Crawler," CBU-TAR-2014-055 Rev. 0, 8/21/14.

[2] SRS Procurement Specification, "H Canyon Recovery Crawler (U)," M-SPP-H-00527 Rev. 0, 1, 2, 9/9/14.

[3] SRS Procurement Requisition, "Recovery Crawler," 0000194379, 9/24/14.

[4] SRS Purchase Order, "H-Canyon Recovery Crawler," SRNS-0000189973 Rev. 0 and 1, 12/17/14.

[5] E. Kriikku, "H-Canyon Recovery Crawler Conceptual Design Approved (U)," SRNL-L4500-2105-00002 Rev. 0, 1/7/15.

[6] A. D. Marzolf, "H Canyon Recovery Crawler Inspection Results," SRNL-L4500-2015-00052 Rev. 0, 6/1/15.

[7] Power Equipment Inc., "Power Equipment Manufacturing Recovery Crawler Operations and Maintenance Manual," 4/27/15.

[8] SRNL eHAP, "H Canyon Recovery Crawler Testing," SRNL-L4500-2015-00048, 5/5/15.

[9] SRNL JHA, "H Canyon Recovery Crawler Testing," SRNL-L4500-2015-00050, 4/24/15.

[10] SRS Final Acceptance Inspection, "Recovery Crawler and associated cable reel, control boxes, and mockup crawler," 4/30/15.

[11] A. D. Marzolf, "Electrical Equipment Safety Evaluation H-Canyon Air Exhaust Tunnel Recovery Crawler," E-ESR-H-00104 Rev. 1, 7/21/15.

[12] SRS Final Acceptance Inspection, "The Recovery Crawler Spray Wand," 4/30/15.

[13] SRS Final Acceptance Inspection, "Recovery Crawler Testing will use the crew trailer, red power distribution box, cables, and surrounding area," 4/28/15.

[14] G. H. Fisher, "Electrical Safety Evaluation of Model TPC-45-S03 Temporary Power Center (U)," E-ESR-A-00125 Rev. 0, 6/25/15.

[15] SRNL R&D Directions, "H-Canyon Recovery Crawler System," 5/4/15.

[16] SRNL Work Instructions, "Operating the Recovery Crawler," WI-RDE-2015-0004, 5/5/15.

[17] E. Kriikku, "H-Canyon Recovery Crawler Test Plan," SRNL-L4500-2015-00007 Rev. 0, 4/27/15.

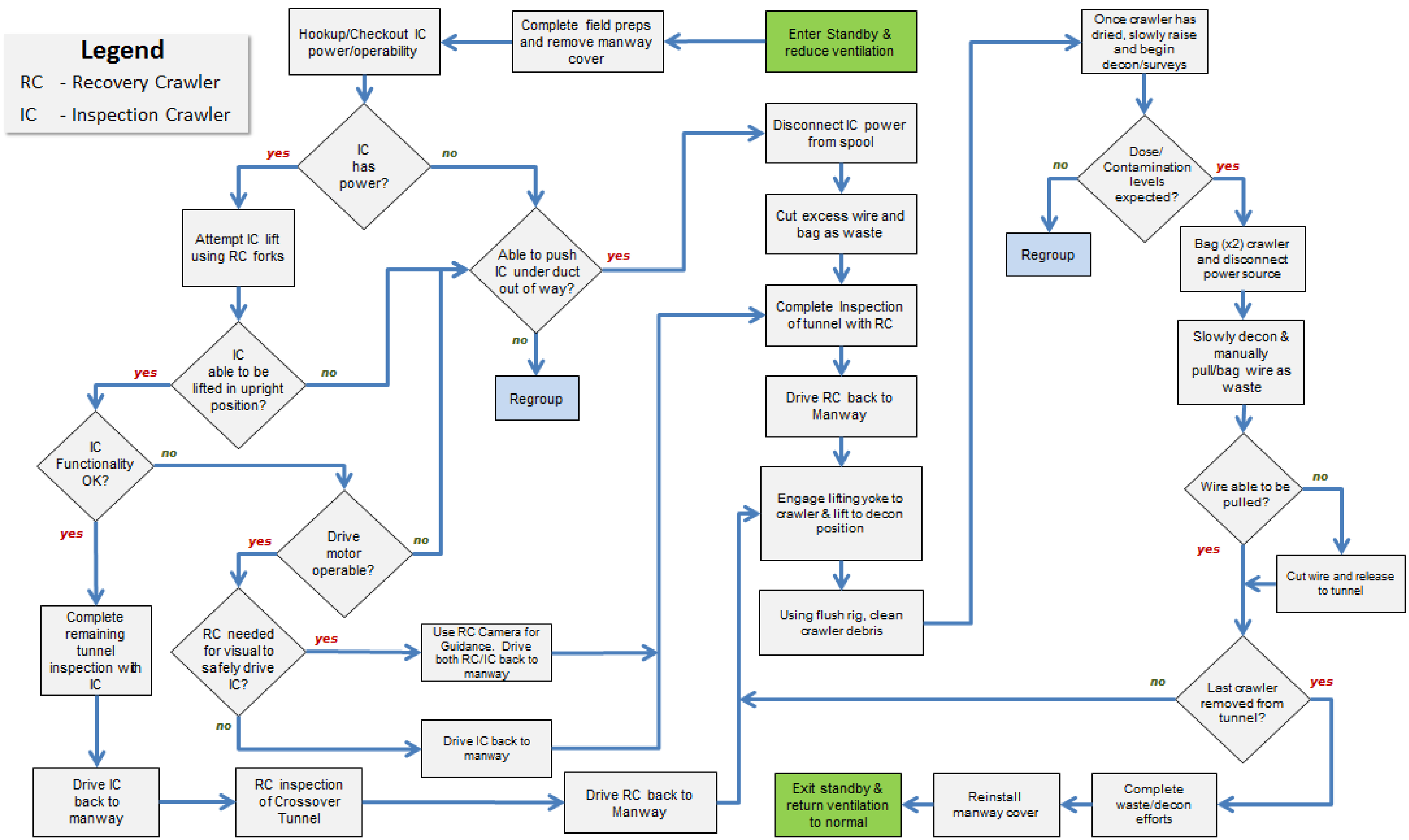
[18] R. F. Fogle, J. R. Gordon, "A Review of the H-Canyon Air Exhaust Tunnel Recovery Crawler," SRNL-L2100-2015-00037 Rev. 0, 5/7/15.

[19] E. M. Kriikku, "H-Canyon Recovery Crawler Test Plan," SRNL-L4500-2015-00007 Rev. 0, 4/28/15.

[20] SRS MSDS 47203-1, "Rust-Oleum Corporation, Neverwet Aerosol (KIT)," 9/9/13.

[21] SRS MSDS 48609-1, "Rust-Oleum Corporation, Neverwet Boot and Shoe," 6/9/14.

Appendix A – Crawler Recovery Decision Tree



Appendix B– Recovery Crawler Sole Source Justification

OSR 1-118 (Rev 4-28-2014)

Sole Source/Single Source Justification

This form is to be used to justify Sole Source/Single Source procurements as discussed in the 7B Requisitio ing Manual, Procedure 1.1

Purchase Requisition Number or Data Sheet Requisition Number	Date
0000194379	**9/9/2014**

Name of Supplier / Manufacturer

Power Equipment Manufacturing Inc.

1. Description of the Requirement

See attached sheet

2. What is the Anticipated Cost/Price?

$70,000, see the attached sheet

3. Has a Market Survey been conducted and what was the result? (Attach Results)

See attached sheet

4. Why or What circumstances necessitate a Sole Source or Selected Source?
See Instructions Sheet for examples that the government considers as exceptions.

See attached sheet

5. What Actions/Events will be made to preclude a Sole Source/Selected Source in the future?

None required, this is a project specific item associated with inspecting the H-Canyon Air Exhaust Tunnel

	Printed Name	User ID	Approval	Date
Originator	**Bill Giddings**	o9361	Signature on file	9/9/14
Originator's Manager	**Mike Lewczyk**	o9200	Signature on file	9/10/2014
Competition Advocate				

☐ **Selected Source for product's/service's entire life cycle (e.g., software renewals)**

☐ **Selected Source for this purchase of product/service (e.g., release against subcontract)**

☐ **Sole Source procurement from only one supplier or manufacturer**

OSR 1-118 (Rev 4-28-2014)
Continuation Sheet

Sole Source/Single Source Justification
(Continuation Sheet)

Purchase Requisition Number / Data Sheet Requisition Number	Date of Requisition
0000194379	9/9/2014
Name of Supplier / Manufacturer: Power Equipment Manufacturing Inc.	
Additional Comments	

Sole Source/Single Source Justification Attachment

Purchase Requisition Number 0000194379

1. Description of the Requirement

As required by the H-Canyon Safety Basis for continued operations, the Structural Integrity Program requires periodic inspections of the various critical support structures in the canyon building and surrounding support areas. This includes the Ventilation System underground exhaust tunnel (an underground concrete tunnel that connects H-Canyon with the sand filter), which has many areas that are not easily inspected due to location and the environment. In 2013, SRNS began to pursue a remote means to inspect the H-Canyon Air Exhaust Tunnel. SRNS purchased an inspection crawler from Power Equipment Manufacturing (PEM) Inc. through the competitive bid process; see RFQ SRNS-0000003436 and Purchase Order 115522 (Requisition # 0000127735). The production cycle for the inspection crawler was 4 months. The Inspection crawler was received in November 2013 and a three month mockup and familiarization period ensued. SRNS started the tunnel inspection in June of 2014 and after completing a large portion of the planned inspection, the inspection crawler fell on its side. The crawler is unable to right itself and it is too far into the tunnel (approximately 320 feet) to pull it out due to the long distance and tunnel interior interferences

SRNS needs to get the inspection crawler back on its wheels so it can be driven tunnel entry point, decontaminated, and stored for future inspections. Another determining factor is the need to have the recovery crawler available by the time of the next outage period for the canyon. Timely removal of the inspection crawler is vital because of the harsh environment inside the tunnel (acid and radiological) than this is expected to over time damage the fallen crawler.

2. What is the Anticipated Cost / Price?

SRNS told Power Equipment Manufacturing that the Inspection Crawler fell over during the inspection. Power Equipment Manufacturing provided an unsolicited estimate of $53K for a recovery crawler. SRNS assumes more features will be added to the recovery crawler, so the estimated cost is $70K. This includes the vehicle, a 700 foot tether, cable reel, and a control system.

3. Has a Market Survey been conducted and what was the result?

The market survey showed a remote crawler with similar capabilities made by iRobot or Remotec will cost more than $200,000. iRobot provided an estimated cost during a phone call and the Remotec price is based on a previous SRS procurement. The Inuktin bid for the Inspection Crawler was approximately $130K.

4. Why or What circumstances necessitate a Sole Source or Selected Source?

Power Equipment Manufacturing is uniquely qualified to provide the recover crawler since they own the proprietary information needed to recover the inspection crawler. SRNS will require the recovery crawler to retrieve the inspection crawler without damaging it. This will require a detailed knowledge of acceptable lift points and unacceptable lift points for the inspection crawler as well as the limitation of the camera support structure for the inspection crawler. SRNS required a concept diagram, electrical schematics, and manuals with the original inspection crawler, so SRNS does not own the detailed design

Sole Source/Single Source Justification Attachment
Purchase Requisition Number 0000194379

drawings. Without these drawings, all other potential suppliers will have to purchase them from Power Equipment Manufacturing. Power Equipment Manufacturing can refuse to sell this information.

Power Equipment Manufacturing is the only supplier that can meet all the requirements. SRNS will require the control system and tether to be interchangeable between the inspection crawler and the recovery crawler. Without the detailed proprietary Power Equipment Manufacturing information, other suppliers will not be able to meet this requirement.

Power Equipment Manufacturing has delivered a quality product on a previous SRNS procurement. Power Equipment Manufacturing provided the inspection crawler and has proposed a recovery crawler based on the same base vehicle. SRNS is satisfied with the inspection crawler's performance in mock-up testing and in the Air Tunnel hazardous environment. SRNS personnel have been trained on the Power Equipment Manufacturing operating system, so further training will be minimized for the recovery crawler. **Power Equipment Manufacturing is the only entity we have found that has an available proven crawler design meeting performance requirements and can deliver in an efficient manner.**

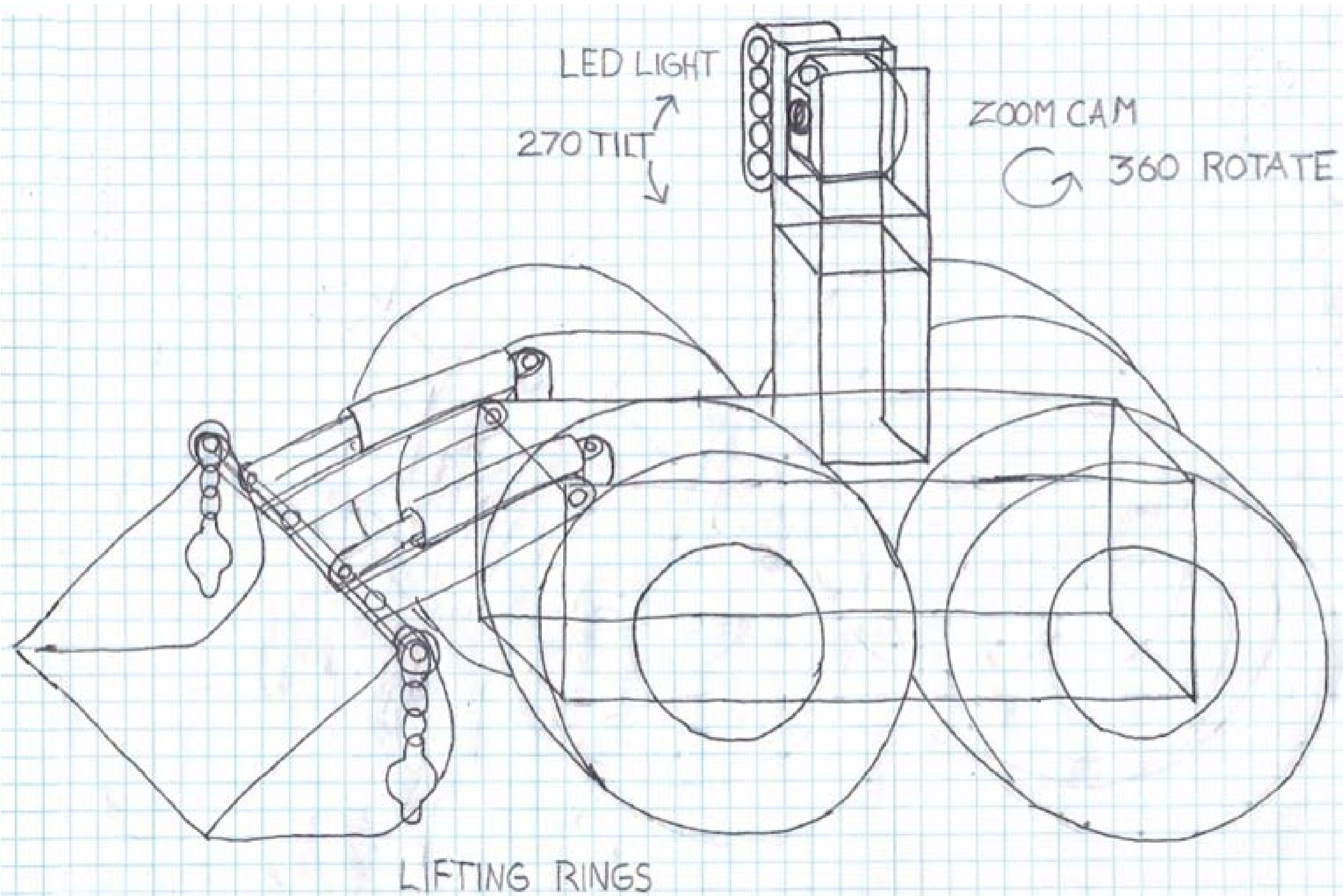
SRNS is expected to meet contractual responsibility for ensuring timely program performance to meet the DOE / NNSA production schedule. To **Compete** the procurement would introduce increased risk and interface concerns. The other considerations for the sole source are shown as follows:

- To effectively recover the inspection crawler there is a need for knowledge of the fallen crawlers weight distribution
- The Power Equipment Manufacturing crawler is a proven technology for the environment in the exhaust tunnel
- SRNS personnel have been trained on the PEM controls and completed several mockup demonstrations using the PEM crawler controls
- SRNS successfully completed testing that proves the PEM crawler tether can be decontaminated
- To provide the most flexibility for future operations, the PEM control concept for the recovery crawler would be interchangeable with the inspection crawler
- SRNS would like the power distribution to be similar between units, so we can marry up to our existing components
- A different vendor would most likely have to talk to the existing vendor on specifics associated with the fallen crawler, which we do not have. This includes a detail design of the unit which is proprietary

This procurement serves to mitigate risk and interface issues / constraints. It also allows SRNS to be ready as soon as possible to recover the inspection crawler without a long series of additional mockup testing and in proving that another design will work in the harsh and challenging environment.

Delaying procurement would increase unnecessary delays in resolving operational issues associated with a new crawler design. From previous discussions with various crawler equipment manufacturers, SRNS concluded that PEM is the only company able to provide a recovery crawler that will reduce the risk and interface concerns

Appendix C - Power Equipment Manufacturing Conceptual Design Sketch



Appendix D - Recovery Crawler Bill of Laden

Bill of Laden 4/28/15
Contract # DE-AC09-08SR22470
Purchase order # SRNS-00169973R1

Delivery of Equipment from

Vendor 0000004022
Power Equipment Mfg. Inc.
2144 Delano St.
Pensacola, FL. 32505

To

U. S. Department of Energy
723-A building
Aiken, SC 29808
Bill Gidings, Eric Kriikku, Sam Newton

One pallet containing the following equipment.
1 box with cables, bulk head panel.
1 box with control panel
1 box with TV reel control
1 box with bucket accessories
1 pallet with TV Reel, Inspection Crawler, Dummy mock up crawler.

Signature on file

ERIC KRIIKKU DATE

Signature on file

Rich Stevens

POWER EQUIPMENT DELIVERABLES

CAMERA CONTROL BOX — EK 4/30/15

REEL CONTROL BOX — EK 4/30/15

CABLE REEL-120vac w/700ft CABLE — EK 4/30/15

25ft-REEL TO BULKHEAD FITTING — EK 4/30/15

25ft-REEL TO BULKHEAD FITTING — EK 4/30/15

75ft-CONTROLLER TO BULKHEAD — EK 4/30/15

75ft-CONTROLLER TO BULKHEAD — EK 4/30/15

INSPC. CRAWLER & CAMERA — EK 4/30/15

BULKHEAD FITTINGS — EK 4/30/15

Documentation of electrical schematics and
Operation/Maintenance/Service manuals — EK 4/30/15

Dummy Mock up — EK 4/30/15

Signature on file

Appendix E - H-Canyon Exhaust Tunnel Crawler Routes