Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-09SR22505 with the U.S. Department of Energy (DOE) National Nuclear Security Administration (NA).

Failure Evaluation of Savannah River Site High-Level Waste Evaporator 242-25H – Part I
17366

Author: T. Yamamoto
Savannah River Remediation LLC

ABSTRACT
A slow leak was discovered in the Savannah River Site (SRS) 242-25H Evaporator (25H) in February 2016. Part I discusses the physical investigation to determine the nature and location of the leak site. Part II separately discusses the analytical work to determine the most plausible failure modes.

The following investigation methods have been used to aid in determining the leak location:

- Remote visual inspection: using remote cameras, inspection of both the inside of the evaporator pot and the evaporator cell, to see if leak locations are visible. Also, inspect the stainless steel insulation jacket for visible leakage.
- Leak level check: filling the evaporator pot with flush water to determine at what elevation the pot stops leaking.
- Enhanced remote visual inspection: utilizing dye penetrant on the inside of the evaporator pot, attempting to see if any defects in the primary containment are visible.
- Grey Qb Gamma camera survey: to look for high radiation areas in the insulation of the evaporator pot.

Parallel efforts are underway to develop a strategy for remotely removing the evaporator stainless steel lagging and insulation, locating the specific leak site and developing a repair method; and repairing the leak site if practicable.

INTRODUCTION

The Tank Farms have received over 605.6 million liters (160 million gallons) of radioactive waste from canyon operations starting in 1954 to the present. Tank Farms operations have reduced the volume of waste via evaporation and dispositioned waste via vitrification and saltstone. The Tank Farms currently store approximately 136 million liters (36 million gallons) of waste containing approximately 250 million curies (MCi) of radioactivity. The evaporators still play a vital role in the SRS mission of cleaning up the stored liquid waste tanks [1].

The 25H Evaporator system at SRS evaporates water from liquid radioactive waste to manage waste storage space in the tank. The evaporator concentrates both high- and low-heat liquid wastes from various feed sources consisting of mainly water and a variety of radionuclides along with some inorganic salts in soluble or suspended form. The overhead vapors are decontaminated to a level such that the condensed vapors meet the feed acceptance criteria for the Effluent Treatment Facility (ETF). The 25H facility and equipment had a design life of 30 years, were constructed in the late 90s, and have been operational since the beginning of 2000 [2].

On February 17, 2016, a leak was discovered at the 25H Evaporator, allowing waste out of the evaporator vessel primary containment into the secondary concrete, stainless steel lined containment cell. The waste that leaked from the 25H Evaporator was contained within its cell. Due to the evaporator pot having a stainless steel seal welded insulation jacket, locating the specific leak location has been masked by the insulation jacket. The following activities have been performed to aid in determining an approximate leak location under the insulation jacket and developing insulation removal and repair methods: clean-up of the cell to reduce contamination; investigation of the possible leak location through visual inspection, dye penetrant and gamma surveys; analyzing the possible failure mechanisms; and researching methods for repairing the vessel leak.

DESCRIPTION

25H is the largest evaporator on site and can create well over 3.78 million liters (1 million gallons) of space gain per year. The original design life of the 25H evaporator is 30 years with operations beginning in 2000. The 25H evaporator operated approximately 16 years before the failure. Previous Savannah River evaporator’s failures have been in the tube bundle region, which required the vessels to be pulled, the tube bundle removed and replaced and the unit placed back into service; or removed and replaced with a new evaporator.

The 25H Evaporator is a 4.27 m (14 ft) diameter, 8 m (26.5 ft) tall, boiler pressure vessel made of Alloy G3, with a normal operating level of approximately 37,475 liters (9,900 gals). The feed pump can send up to 151 Lpm (40 gpm), the steam lift is 172 kpa, at 22.7 kg/hr (25 psig, at 50lb/hr), the steam lance agitates at 172 kpa, at 453.6 kg/hr (25 psig, at 1000 lb/hr), and overheads can be produced between 37.9 to 79.5 Lpm (10 to 21 gpm). The evaporator sits in a secondary containment, the evaporator cell, which is a concrete structure with a stainless steel liner. The evaporator is operated from a central control room with a distributed control system (DCS) [2].

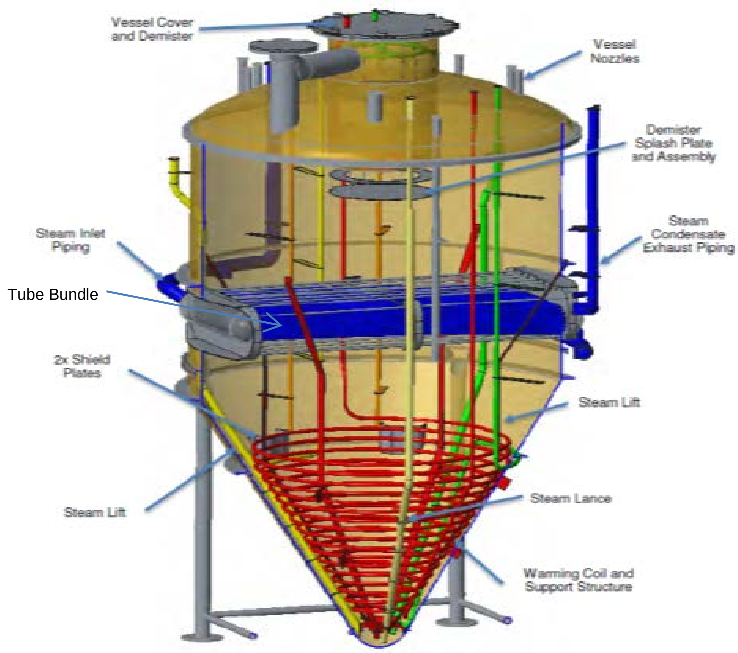

Fig. 1. Major Components of the 25H Evaporator [2]

The steam tube bundle in blue on Figure 1 is comprised of 648 tubes made of Hastelloy G3, with 141.9 m^2 (1,527 ft^2) of effective heat transfer surface area. The unit can be fed between 3,628.7 kg/hr up to 7,257.5 kg/hr at 2240.8 kpa (8,000 up to 16,000 lbm/hr at 325 psig) steam, with each tube being 3.8 m long, 1.905 cm O.D., 0.3658 cm (12.42 ft long, 0.75 in O.D., 0.1455 in wall thickness). The tubes are secured in the tube sheets that are 2 m, wide x .69 m, wide x 5.08 cm, thick (78.75 in wide x 27.25 in tall x 2 in thick) made of Hastelloy G3. The tube bundle is designed with the tubes having a slight curve to allow for condensate to move towards the condensate chest as well as allow for flexing during desalt/descale operations to clean the tube bundles [2].

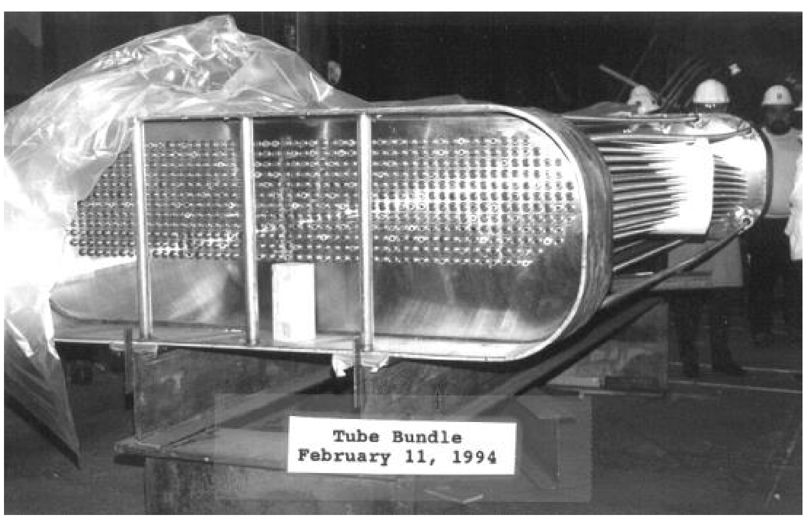

Fig. 2. Steam Tube Bundle

DISCUSSION

The 25H physical investigation developed different methods of internal and external remote investigation to document the exterior and interior including: remote camera inspections; enhanced remote visual inspection with dye penetrant; Grey Qb radioactive visual level inspection; and analysis as discussed below.

Evaporator Pot Level Changes

To begin narrowing down where the potential leak location could be on the 25H Evaporator, SRR started with changing the evaporator pot level to visually see when leaking occurred outside of the insulation jacket. This was accomplished by emptying the pot down to a heel, waiting for the leak to stop and adding water through the lance in lifts, stopping at the section of the evaporator pot where there could be potential for leak locations (i.e. seam welds, stiffening bands, steam tube bundle, etc.) and waiting for a minimum of an hour. Visual inspections occurred during and in between additions, looking for the leak to start after each lift.

This investigation continued until the evaporator was nearly full to the normal operational level without a visual of leaking. The waste stream inside of the vessel has a high specific gravity and is caustic. It was assumed that using cooler water may have allowed some of the salt to drop out of the solution which slowed or plugged the leak path. To create the leak again, additional heat was added via steam through the lance, which warmed the liquid enough to initiate the leak. To narrow down the leak location, the vessel was allowed to leak until the indicated level change stopped. The approximate location where the leak slowed and eventually stopped was near the middle of the tube bundle with an average leak rate of 378 L/day (100 gallons/day). To validate the location, the process was repeated; leakage stopped the second time at a slightly higher location, closer to the upper portion of the tube bundle.

The stopping of the leak and the change in potential leak location may have been a result of the salt dropping out of solution causing and altering the leak path. Additionally, the amount of head pressure needed inside of the vessel to propagate the liquid through the wall of the evaporator, through the 5.08 cm (2 in) of calcium silicate and out of the insulation jacket leg hole opening may have contributed to the change to the potential leak location.

Fig. 3. Construction of 25H Evaporator Vessel

External Physical Remote Examination

A remote examination of the exterior of the evaporator vessel was conducted to document the construction of the lagging on the evaporator. There are detailed construction drawings of the evaporator vessel, but insulation and lagging was installed when the vessel was installed in the cell. The general requirements for insulation and lagging are documented, but not the specific details of how the lagging was configured on the evaporator. The exterior examinations helped to document and observe additional details of how the lagging was assembled and held to the evaporator vessel. From the drawings, most of the stiffening bands were stitch welded onto the vessel. However, per the fabrication drawings, the support ring is seal welded on the bottom side and stich welded on the top, Figure 3, separating the cone from the vertical section of the evaporator.

The examination of the exterior walls showed liquid and salt waste coming out of the north-west and north-east leg openings of the evaporator vessel. This location is just below the support ring (see Figure 4.) that segregates the cone from the vertical section of the evaporator. The exterior exam did not indicate any location where the lagging allowed a path to go around the stiffening band. The leak location contradicts where the indicated level stopped during the previous leak test.

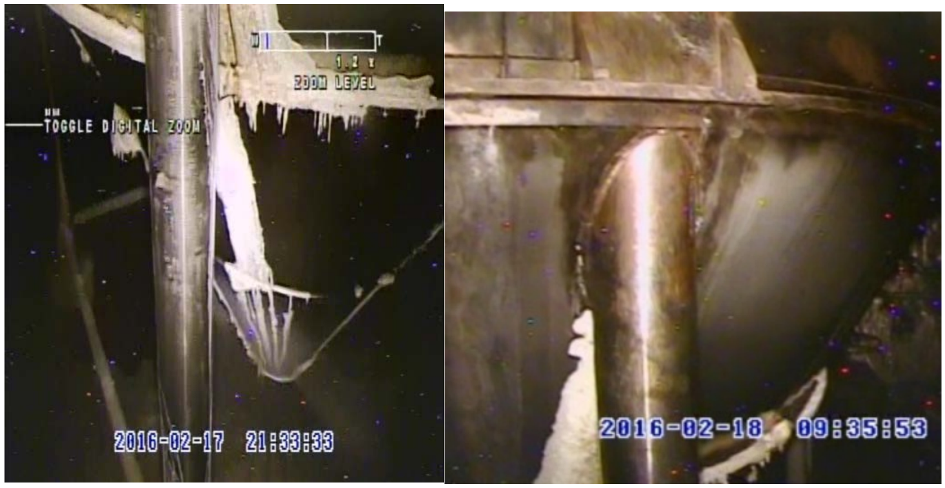

Fig. 4. Figure on the left shows visible salt deposits on the lagging of the evaporator vessel. Figure on the right shows one of the location where the leak is coming out of the vessel lagging where the leg penetrates thru.

Internal Physical Remote Examination

After the cell was flushed and cleaned, an internal examination of the evaporator was performed looking for abnormalities, deformations, and discrepancies. The focus of the internal examination were areas near the tube bundle, welded seams, near where the legs are welded, and other joints. A desalt/descale operation (D&D) was not performed on 25H before inspection to clean the tube bundle. However, filling and lowering the level did wash a majority of the vessel, leaving only trace amounts of material on the interior surface.

The internal examination showed some areas of interest with light markings, linear marks with salt deposits, and brackets that could potentially cause wearing. However, there were no specific locations that indicated a leak from the internal examination. The locations of interest were used to guide the next activity of an internal enhanced remote dye penetrant examination.

Internal Enhanced Remote Dye Penetrant Examination

After the internal examination was completed, the team developed a water washable remote dye penetrant system. The unit was comprised of a water lance for flushing, and a dye lance for application attached on a remote camera with a pan and tilt function to direct the flow (See Figure 5.). The remote dye penetrant tool was lowered through the S6 port to examine the areas south of the tube bundle. A separate tool and camera were lowered through the Y3 and Y4 ports to examine the north side of the tube bundle with the camera utilizing the opposite port for inspection. The dye and water were sprayed with peristaltic pumps that would be turned on and off to initiate spraying. It was applied to the surface at an area of interest and allowed to sit for at least 20 minutes then reapplied as needed to keep the surface wet. After the 20 minute dwell time, the area of interest was flushed and the camera was focused on the area of interest looking for small deformations where the dye may weep out.

The majority of the north side of the evaporator from the middle of the evaporator down was sprayed with dye and washed. Additional enhanced visual inspections with dye penetrant were performed on the tube bundle looking where the tube sheet was welded to the vessel. There were no specific locations that indicated a leak from the enhanced visual inspection with the dye penetrant. Figure 6 shows all of the areas of interest where dye was applied and the chart gives a description of the individual locations.

Fig. 5. Figure on the left is the dye penetrant application unit with a dye and flush lance attached to a remote camera. Figure on the right is the top of the steam tube bundle with dye penetrant on the surface before flushing.

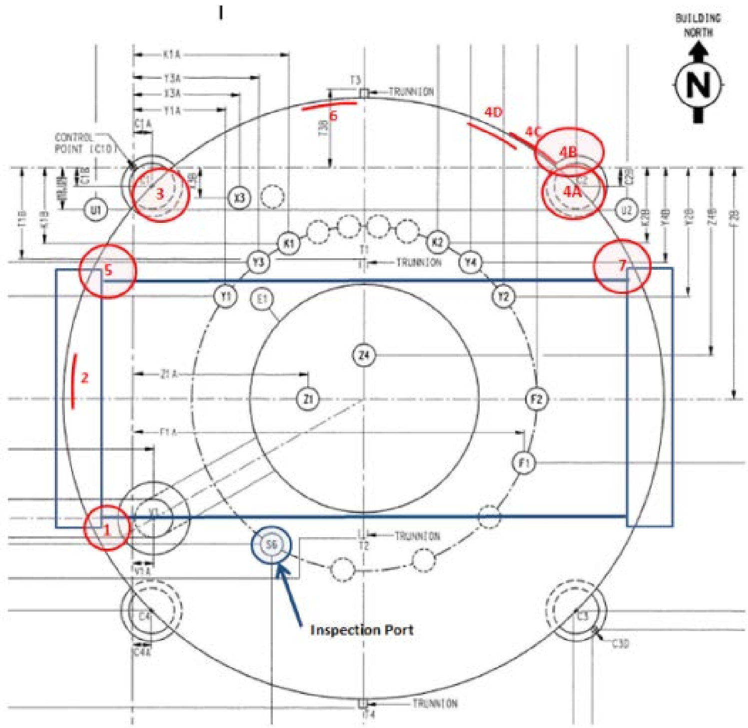

Fig. 6. Dye Penetrant Locations sprayed.

South Inspection Port
1. Tube Bundle Inlet
2. Seam below the weld line where the body is welded to the cone.
3. Northwest corner, Leg connection
4. Northeast corner
    A. Leg connection
    B. Rough patch above leg connection
    C. Weld line near leg connection
    D. Seam just below the weld line where the body is welded to the cone.

North Inspection Ports
5. Tube Bundle Inlet
6. Steam Lift Supports
7. Tube Bundle Outlet

External Grey Qb Examination

To aid in determining whether or not the leak was in the lower or upper section of the evaporator vessel, a Grey Qb was used to detect radioactive gamma hot spots. The Grey Qb, consisted of a 3D printed housing, a Go-Pro camera, and a tungsten shielded x-ray film shown in Figure 7. Around the Grey Qb was a shielded case with a shutter. The unit would be lowered into position and the shutter door would be raised exposing the x-ray film, while the Go-Pro camera took images. Once the exposure time was complete (~20 minutes), the shutter was closed and the unit retrieved. The x-ray film and the images were imported to software that overlaid the images to show areas with the highest exposure. Separate shots were able to be evaluated against one another, comparing the intensity values within the exposed image.

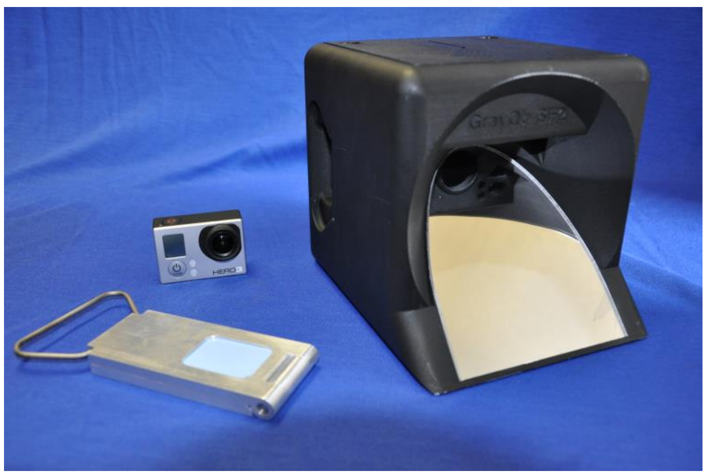

Fig. 7. Grey Qb Developed by SRNL.

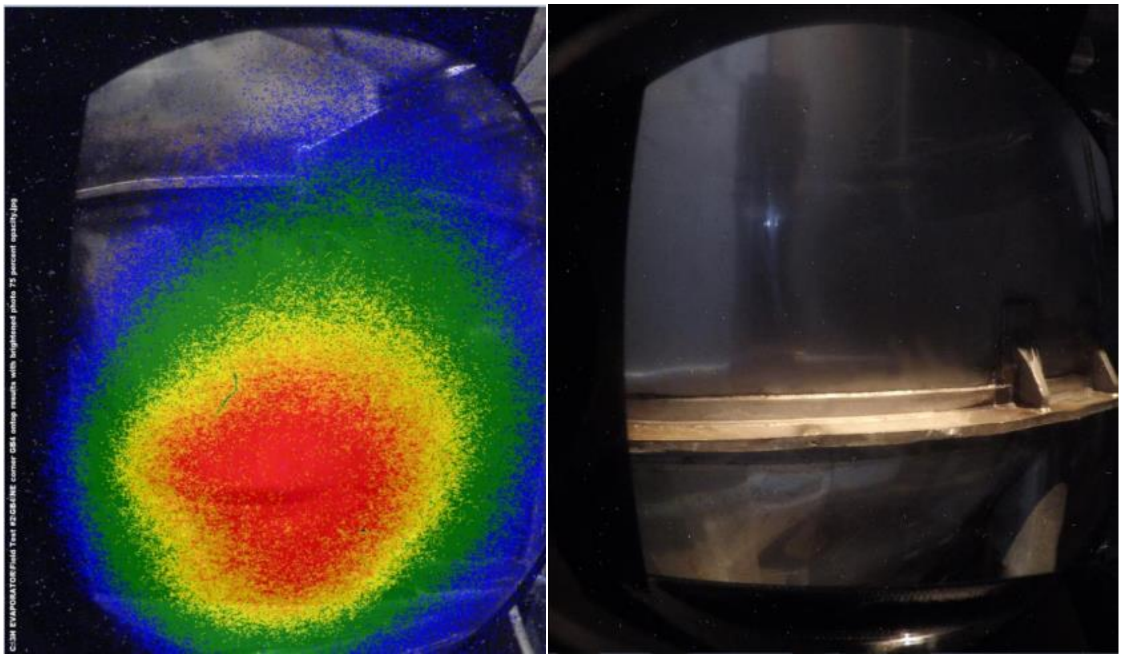

Fig. 8. Figure on the left shows the activity spot in the lower cone section of the evaporator. Figure on the right shows an adjusted image that is scaled to the hot spot on the left image, which resulted in intensity level of the image on the right to have a background value with no values reaching the colored portion of the image.

The results from the Grey QB indicated that there was a very intense concentration of radioactive material in the lower section of the evaporator pot, and background radiation levels in the upper portion (See Fig. 8.). If a leak were to occur in the upper section of the evaporator near the tube bundle, one would anticipate an area with higher radiation levels that would indicate more intensely near the stiffening band that segregates the upper vertical section from the lower coned section. However, that was not observed in the image.

Failure Analysis

In parallel with the physical investigation, another team was tasked with analyzing the vessel to determine any potential locations where the leak could occur. A Finite Element Analysis (FEA) identified areas with large temperature gradients over small distances where the shell joins the tubesheets and the evaporator vessel. The calculated stresses exceed yield during tube-bundle descaling operations. Additionally an investigation considered the lower section of the evaporator pot. The steam lift lines and the warming coil guide plates could rub against the vessel and wear a hole in the vessel from rubbing [3]. Part II will provide more detail of the analysis.

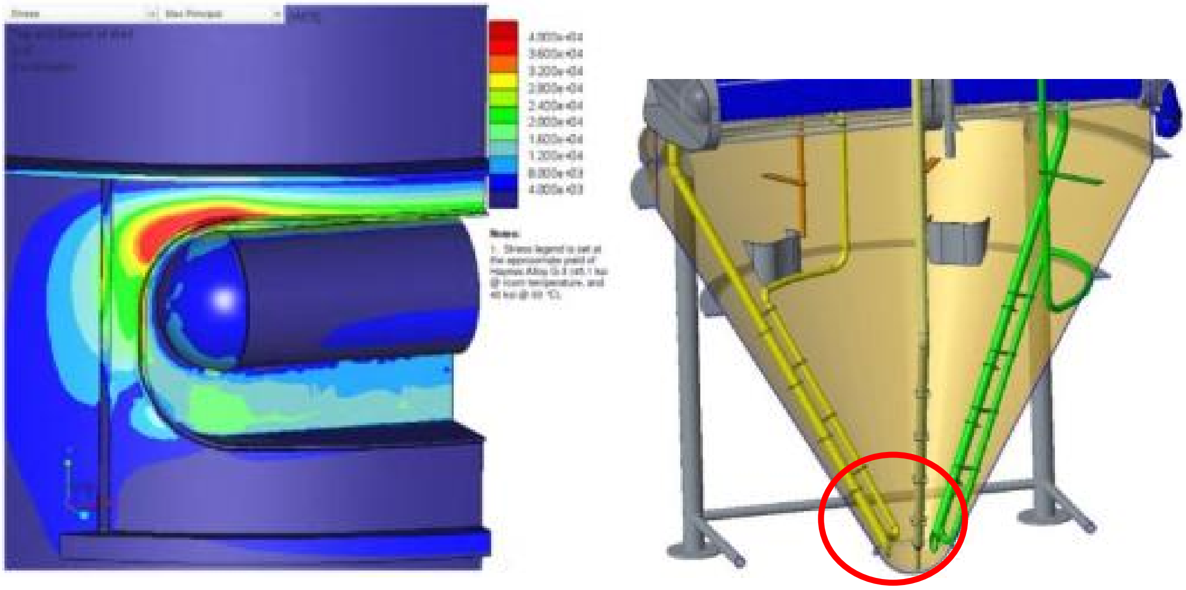

Fig. 9. Figure on the left indicates in red the high stress point where the tight radius of the tube sheet is welded to the evaporator vessel. Figure on the left shows where the lift has the opportunity, when thermally growing, to interfere with the body of the vessel and could cause wearing and eventually a leak. Developed by AECOM.

Remote Equipment

From the physical investigation coupled with the failure analysis, it was determined that the leak could be coming from the lower section of the evaporator pot:

- Due to the physical evidence of no salt being on or above the 94 cm (37 in) support ring that separates the upper vertical section from the lower cone.
- Salt exiting the lagging at the leg openings below the 94 cm (37 in) support ring.
- The seal weld at the support ring
- The Grey QB showing significant source term in the cone, and undistinguishable levels above.

Some evidence that contradicts the leak location determination:

- The high stress level analyzed near the tube bundle.
- The leak investigation showing the level stopping in the middle of the tube bundle.
    - o The leak could have been impacted by salt forming around the leak site causing the leak to stop premature of the actual level.

With the leak anticipated in the lower section, the project moved forward with the development of remote equipment to remove the insulation and lagging from the cone section of the evaporator pot.

Development of remote equipment to cut the lagging and remove the insulation from the lower section of the evaporator is in progress. A BROKK 100 (remote excavator) with a KUKA machine assembly robot arm attached to a platform on the end of the BROKK will be used. The unit will be lowered into the cell via a crane platform with the BROKK positioning the arm close enough to the evaporator to remove the lagging and insulation. It is anticipated that the KUKA will be fitted with a plasma torch to cut pieces of the lagging. Once all or sections of the lagging are cut and removed from the cell. The robot will then be raised out of the cell and a separate end effector will be placed on the KUKA with a tool changer and multiple tools to remove the bulk of the insulation.

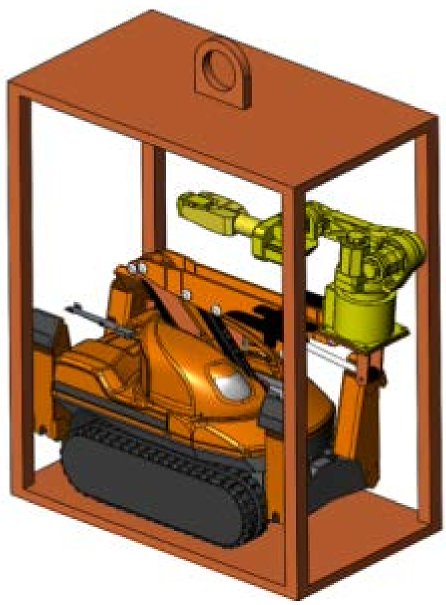

Fig. 10. Figure on the left shows a model of the BROKK 100 with the KUKA arm attached to the robot on the lifting mechanism that will lower and raise the unit out of the cell. Figure on the right shows a typical BROKK 100 with some of the other attachements that readily available for the BROKK if needed.

Once all of the insulation and lagging are removed from the evaporator vessel and the cell is cleaned, the vessel will be filled with water to see if the leak can be visually located. If the vessel needs to be heated, the steam lance or tube bundle will be utilized to add additional heat. It is anticipated that the leak site is going to be difficult to find, with the leak site anticipated to be very small due to the slow leak rate of approximately 378.5 liters/day (100 gallons/day). However, once the leak site is located, the local area around the leak will be further cleaned by remote equipment. This will aid in repairing the vessel. Remote equipment is currently being developed and designed for the repair.

CONCLUSIONS

From the evaluation - it is anticipated that the leak site is located in the lower cone section of the evaporator vessel. Although the high stress level analyzed near the tube bundle and the leak investigation showing the level stopping in the middle of the tube bundle contradict the location in the lower section of the evaporator vessel, the physical evidence does not support a leak in the upper section of the evaporator.

Therefore, preparations for removing the insulation and lagging from the lower section of the evaporator vessel have begun. Activities include: site preparations, robot assembly, robot testing, procuring and locating necessary support equipment, waste disposal and transportation planning, radiological contamination control planning, design and construction of a bridge walkway over the cell, and work control planning. The tentative schedule has the assembly of the robot complete in early November; with it being onsite and showcasing its capabilities by mid-November; with the removal of lagging and insulation to begin by end of November/early December; and the detection of the leak middle to end of December.

REFERENCES

1. Chew, D.P. and B.A. Hamm, *Liquid Waste System Plan Revision 20,* SRR-LWP-2009-00001, Rev. 20, Savannah River Remediation, LLC, 2016.
2. Kennedy, W.N. and Martin, D.J., *Replacement High Level Waste Evaporator System Design Description,* G-SYD-H-00026, Rev. 4, Westinghouse Savannah River Company, 2003
3. Wunderlich, G. and S. Gingrich, G. Denavit, "*RR 3H Evaporator Failure Analysis*, AECOM Study No. 31446-15-ST-0001, Rev.0, June 22, 2016.
4. Keilers, C., Wierssma, B., Schwenker, J. Yamamoto, T., *Failure Evaluation of Savannah River Site High – Level Waste Evaporator 242-25H – Part II – 17353*, Savannah River Remediation, LLC, 2016.