PIT-MISC-0040



# Tank 19 Heel Removal Systems Engineering Evaluation

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## Waste Removal Programs

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# 1.0 Introduction

DOE-SR proposed an incentive to WSRC in September 1998 to complete heel removal from Tank 19 before the end of FY99. This informal Systems Engineering Evaluation was performed during October 1998 to quickly determine the technology to be used to remove the sludge and zeolite heel. While the short time constraint limited the degree to which the standard Systems Engineering approach could be employed, the evaluation team is of the opinion that the evaluation was sufficiently thorough to achieve the stated objective.

# 2.0 Program Objectives

WSRC HLW and DOE-SR have agreed on Performance Based Incentives regarding the removal of the sludge and zeolite heel in Tank 19. There are two components to the PBI that are stated in simplified terms below. A copy of the signed PBI is included as Attachment A.

- Initiate heel removal by 7/30/99 - $400,000
- Complete heel removal by 9/30/99 - $350,000

It is the objective of WSRC HLW to develop a project strategy that provides the minimum essential facilities to support achieving the PBI. As such, the objectives of the Tank 19 Heel Removal Program are as follows:

- design, build and deploy heel removal equipment in Tank 19
- initiate heel removal operations by 5/30/99
- complete heel removal operations by 9/30/99

The 5/30/99 date is a self-imposed target date intended to maximize achievement of the 2nd component of the PBI.

# 3.0 Program Description

Tank 19 currently contains an estimated 13,000 gallons of zeolite, 13,000 gallons of saltcake and 7,000 gallons of sludge for a total of 33,000 gallons of solids. This material was left in the tank after a salt removal campaign that removed over 900,000 gallons of saltcake. Two standard slurry pumps were used at the end of that campaign. No attempt was made to remove 33,000 gallon solids heel.

There are a wide variety of technologies that could be used for heel removal. It is the general consensus that no one technology will efficiently remove the 33,000 gallon heel such that a small volume of solids remain that can be deemed incidental waste. For this reason, heel removal is divided into two phases: bulk heel removal and residual heel removal. Phase I bulk heel removal is defined for Tank 19 as removing the waste from 33,000 gallons down to <2,000 gallons. Phase II residual heel removal is defined as waste removal from 2,000 gallons down to the calculated volume that can be declared incidental waste. The <2,000 gallon value was determined to be the goal of Phase I based on Tanks 17 and 20 experience.

A Systems Engineering approach will be used to separately select the Phase I and Phase II technologies. A small team of subject matter experts was established to select the technologies. The selection process involved reviewing existing heel removal options, brainstorming new heel removal options, accurately defining each option, developing selection criteria, accurately defining each selection criteria, establishing weighting factors for the criteria, and then scoring each option per the selection criteria to obtain the recommended option. This process was followed for each phase. The results of the Phase I selection process are presented in this document.

## 4.0 Evaluation Team Composition

A cross-functional team was selected to perform the Systems Engineering Evaluation.

| Name | Department | Functions |
|---|---|---|
| Tom Caldwell | CST WRP Engineering | Waste Removal Design Authority, New Technologies, Fluid Dynamics |
| Phil Rodwell | CST TFA Engineering | Tank Closure, New Technologies, Instrumentation |
| Ed Howard | Design Engineering | Prime Interface with DE |
| Joe Cato | HLW Maintenance | Tank Closure, Tank Farm Operations, Mechanical Equipment |
| Toby Hess | Waste Removal Project Liaison | Waste Removal design, Electrical and Instrument design |
| Neil Davis | Waste Removal Program Manager | Systems Engineering, Program Planning, Waste Removal |

The results of the Systems Engineering Evaluation will be peer reviewed to ensure technical objectivity and to ensure that key concerns have not been overlooked:

| | |
|---|---|
| • Jeff Newman | CST Environmental Engineering |
| • Lee Carey | PE & CD Design Engineering |
| • Harvey Handfinger | HLW Maintenance, late of Tank Closure |
| • Jerry Morin | HLW Technical Director |
| • Eloy Saldivar | Principle Investigator for the TFA, Waste Removal Design Authority |

# 5.0 Selection Criteria Definition

**Cost**
Estimated total cost of design, construction and operation. It is recognized that some of the options will have a very low quality estimate. Scoring on a scale from 1 to 5 will be assigned as follows:

1 = >$1,500,000
2 = $1,000,000 – 1,500000
3 = $750,000 – 1,000,000
4 = $500,000 – 750,000
5 = <$500,000

**Schedule**
For Phase I, this criterion reflects the degree of confidence that the option can be operational by 5/30/99 and finished by 7/31/99. Higher confidence warrants a higher score. **A score of 1 on the 1 to 5 scale for this criterion will preclude an option from further consideration.**

**Testing**
This criterion reflects the degree of testing deemed necessary to perform prior to start of operation. Testing includes equipment, process and operational modes but not testing strictly aimed at optimization. More required testing warrants a lower score.

**Infrastructure**
This criterion is based on the degree to which new infrastructure is required to implement the option. Infrastructure is defined as services (water, steam, compressed air, cooling, etc.) or human resources support (crews to perform complex maintenance or operations tasks). If an option requires no new infrastructure, then it gets a high score.

**RadCon**
This criterion concerns the degree to which new hazards are introduced by the option. Hazards include radiation exposure to personnel, potential for contamination release, exposure to hazardous chemicals, etc. Higher exposure to hazards gets lower score.

**Downstream Impacts**
This criterion is a measure of the impacts introduced by the option to other facilities or processes. Impacts include chemical, radiological source term, other unanalyzed properties, introduction of an additional process step, introduction of a new waste stream, etc. The greater the impacts, the lower the score.

**Effect on Key Resources**
This criterion is a measure of the impacts to key human resources. These resources include DA, DE, Operations, and possibly others. The greater the impacts, the lower the score.

**Probability of Success**
This criterion is a subjective judgement as to the likelihood that an option will satisfy the objectives of the heel removal program. The equipment and/or process is assumed to work as designed in this criterion. Reliability and maturity issues are covered by other criterion. The greater the likelihood of success, the higher the score. The ability of an option to accommodate unforeseen conditions also contributes to a higher score. **A score of 1 on the 1 to 5 scale for this criterion will preclude an option from further consideration.**

**Reliability**
This criterion is a subjective judgement as to the likelihood that the equipment or process will be operable 80% of the time or more for the duration of the heel removal operation as well as a judgement as to the maintainability of the equipment. Low perceived reliability gets a low score. Increased complexity of the equipment and/or process also contributes to a lower score.

**Maturity**
This criterion is a judgement regarding the maturity of the process or equipment. Equipment that is still in the conceptual design phase would tend to get low scores whereas equipment that is the industry standard, e.g., is in common use and has been perfected over a number of years, would tend to get high scores.

# 6.0 Option Description

**EMMA**
The "Easily Maneuvered Manipulator Arm" or EMMA is a tubular arm consisting of 2 to 5 sections linked together by flexible joints. The sections are connected by a series of cables that control movement. The arm control user interface is a bank of joysticks. EMMA requires a 24" access opening. Different end effectors can be mounted. The payload is 250 pounds with a maximum reach of 75 feet.

**Delphinus Arm**

This is a heavy-duty manipulator arm with a 75' reach and 3,000 pound payload. It appears to be a very rugged piece of equipment. A 36" access opening is required.

**Light Duty Utility Arm**

This option consists of an articulating arm that can reach down into a tank and then be extended laterally to position a variety of tools (end effectors) to clean out a tank. The LDUA has been modified to increase the payload to 200 pounds. End effectors in use at Oak Ridge consist of water jets and jet pumps to mobilize sludge deposits and then transport the sludge out of the tank. The LDUA or MDUA would need to operate from several different positions to clean out an SRS tank.

**Medium Duty Utility Arm**

See Light Duty Utility Arm above.

**Borehole Miner**

This option consists of a high-pressure water jet discharged from an extendable nozzle. The nozzle is supplied at pressures up to 3,000 psi and can be remotely extended, rotated and angled. This equipment was adapted from the mining industry. The Borehole Miner was developed for Oak Ridge in FY97 and is being demonstrated in FY98.

**Track Pump**

This option involves contracting a ful service vendor to operate a specific piece of equipment to remove the waste heel. The Track Pump is a small remotely controlled` vehicle powered by tracks. Small augers at the front of the tracks funnel sludge solids between the tracks where the pump suction can pick up the sludge and pump it out of the tank.

**ARD**

This option involves contracting with ARD Environmental Services, Inc. to remove the tank heel. ARD would provide operators, maintenance, and RadCon coverage. The cleaning equipment consists of a remotely operated robotic scavenger deployed on the tank floor. Solids are removed by high pressure spraying, grinding, brushing and vacuuming/pumping out of the tank. The scavenger discharge hose would use the soon to be installed containment box to transfer to Tank 18.

**SRS Crawler with Water Brushes**

This is a remotely operated electrically operated tracked platform developed by SRS using TFA funding. This platform is intended to be used with an onboard water monitor although other uses are possible. The basic configuration is the crawler with a water monitor mounted to it supplied with a medium pressure water source. The crawler would spray sludge towards the Pitbull or Goulds pump. The pump(s) have small dikes attached to help funnel the sludge to the pump suction. The effect of the crawler and onboard water monitor would be augmented by roof mounted remotely operated water brushes.

**SRS Crawler with Water Mouse**
This option is similar to the above except that the roof mounted water brushes are replaced by a remotely operated water mouse that is used to flush sludge away from the tank walls to improve the effectiveness of the crawler.

**SRS Crawler with Recirculating Water Monitor**
In this configuration, the crawler would carry its own pump which would draw water from the tank bottom and discharge it through a nozzle to dislodge sludge and propel the sludge to the transfer pumps. The recirculating pump has not yet been developed and tested, however, it is believed that this is a relatively standard pump application.

**Red Zone**
This robotics company provides a remotely operated hydraulic work platform for sale to the nuclear industry. Several tools can be mounted to the platform including a manipulator, plow blade, scoop, spray nozzles and a hydraulic shear. This platform , known as Houdini, has been used at Fernald and the gunite tanks at Oak Ridge. It can be deployed through a 22.5" riser opening. The entire system consists of the platform, tools, a power distribution control unit, a control console, and a tether management system.

**Flygt Baseline**
This option involves installing three 15 HP stationary mixers, three sets of lights, 2 cameras, two tank roof mounted water brushes, three temporary portable power supplies, the Pitbull and Goulds transfer pump and using the soon to be installed Containment Box.

**Flygt Stationary 50 HP Mixers**
This option involves installing three 50 HP stationary mixers, three sets of lights, 2 cameras, two tank roof mounted water brushes, three temporary portable power supplies, the Pitbull and Goulds transfer pump and using the soon to be installed Containment Box. Slurry water could be recycled from Tank 18 to Tank 19.

**Flygt Rotating 50 HP Mixers**
This option involves installing three 50 HP rotating or oscillating mixers, the Pitbull and Goulds transfer pump and using the soon to be installed Containment Box. Slurry water could be recycled from Tank 18 to Tank 19. Residual heel removal may be required by a second step (chemical cleaning, crawler, water monitors, robotics, etc.).

**Refit Bingham Pumps**
This option involves refitting 3 existing Bingham slurry pumps with mechanical seals, re-installing Rotek bearings on three existing spray chambers, installing the pumps, installing the Pitbull and Goulds transfer pumps and using the soon to be installed Containment Box. These slurry pumps do not have machined impellers therefore seal leakage will probably become excessive after several hundred hours of operation. Residual heel removal may be required by a second step (chemical cleaning, crawler, water monitors, robotics, etc.).

**New Lawrence Pumps**
This option includes using 3 new Lawrence slurry pumps of the Tank 8 design, re-installing Rotek bearings on three existing spray chambers, installing the pumps in the three existing spray chambers, installing the Pitbull and Goulds transfer pump and using the soon to be installed Containment Box. These slurry pumps have incorporated all of the lessons learned including machined impellers. Residual heel removal may be required by a second step (chemical cleaning, crawler, water brushes, robotics, etc.).

**Advanced Design Mixer Pump**
This option includes finishing the testing of the existing ADMP at TNX, replacing one or two spray chambers with larger units, installing the ADMP(s), installing new motor drive(s), installing the Pitbull and/or Goulds transfer pump and using the soon to be installed Containment Box. Residual heel removal may be required by a second step (chemical cleaning, crawler, water brushes, robotics, etc).

**New Mini-Quad Volute Pumps**
This option involves funding the vendor to finish development of the mini-quad volute slurry pump, installing 2 pumps in existing spray chambers, installing 2 new drives, installing the Pitbull and/or Goulds transfer pump and using the soon to be installed Containment Box. These slurry pumps would presumably utilize the latest technology similar to the Lawrence pumps. Residual heel removal may be required by a second step (chemical cleaning, crawler, water brushes, robotics, etc).

**AEA Pulse Tube Mixers**
This option includes installing several (6 to 12) pulse tube mixers, providing a rental or packaged compressed air supply, installing the Pitbull and/or Goulds transfer pump and using the soon to be installed Containment Box. Residual heel removal may be required by a second step (chemical cleaning, crawler, water brushes, robotics, etc).

**Chemical Cleaning using Sluicing**
This option involves using dilute (2-4 wt %) heated (90oC) oxalic acid (OA) to dissolve the sludge such that it can be pumped out as was done on Tank 16. The OA is added via water monitors to provide agitation to prevent the formation of a boundary layer. OA forms a passivating layer on carbon steel thus retarding further corrosion. OA dissolves metals first and therefore can concentrate actinides (e.g., Pu) in the remaining sludge. A criticality study is probably required before OA use. OA must be neutralized in the waste tanks which causes the formation of oxalates. The vitrification and saltstone processes can tolerate small amounts of oxalate however, this must be closely controlled.

**Chemical Cleaning using Mixers**
This option is similar to the above except that the OA can be added by gravity flow with mixing provided by one of the above mixer options. The volume of chemical additions would be more than the sluicing option due to the minimum submergence of the mixers, however, the agitation will be much more vigorous.

## 7.0 Selection Criteria Weighting

It is recognized that all criteria are not of equal importance. The team selected the most and least important criteria. The team then subjectively determined that the most important criteria was about1.5 times as important as the least. The weighting factors therefore range from a low of 1.0 to a high of 1.5.

## 8.0 Option Scoring

Each option was awarded a score of between 1 and 5 for each selection criterion. High scores denote that the option is more favorable. The total score for each option is determined by summing the product of the criterion score and the weighting factor for each criterion. Two of the selection criteria were judged to be similar to constraints: Schedule and Probability of Success. A score of 1 for either option effectively eliminates the option from further consideration. If an option is judged to either not meet the schedule or have virtually no chance of success, then there is no need in pursuing that option regardless of how well it may score on the other criteria.

## 9.0 Selection Results

Arms
The arm-based technologies all received a score of 1 in the "Probability of Success" criteria thus they received no further consideration. The low score was attributed to the limited reach of each arm in the 85' diameter 40' deep tank that would probably drive arm deployment in several risers. The arm would have to be capable of pushing or sluicing the sludge to the transfer pump suction. It is believed that significant sludge would be left behind and that repeated "sweeps" of the tank would be required from each riser location.

Robotics
The robotic devices generally scored well. The Track Pump and ARD units were thought to be reliable, robust and mature tools that have wide use in commercial applications thus they scored higher than the recently developed tools such as the SRS crawler. ARD has been used at SRS during the past few years for tank and basin cleaning.

Mixers
Stationary Flygt pumps scored poorly because of the large number of pumps required to eliminate quiet zones in the tank where sludge and zeolite would rapidly resettle. Using standard slurry pumps scored poorly because the effective cleaning radius (ECR) is not adequate given the existing riser locations where these pumps could be deployed. The Advanced Design Mixer pump scored low due the size of the unit and the required

supporting services. This pump could only be installed in the center riser which would require completely redesigning the existing truss. The Mini Quad-Volute pumps would probably work very well however, they are more of a concept than an established design. The AEA pulse tube mixers scored because the low ECR would necessitate the installation of 10 to 20 of these mixers. Rotating 50 hp Flygt mixers were the clear winner in this category. The ECR is sufficient and these mixers have been the subject of testing for the last year.

Chemical Cleaning

These options scored below the best of the robotic and mixer options due to the analytical work required and the legacy waste issues. It is recognized that some form of chemical cleaning may ultimately be needed in Tank 19 and will definitely be needed in tanks with higher source terms.

# 10.0 Recommendation

The team determined that rotating 50 hp Flygt pumps were the preferred option for Phase I with the expectation that residual waste at the end of the Flygt campaign could be easily removed via chemical cleaning or robotics. The follow-on process after Phase I, if needed, will be the subject of a separate Phase II evaluation.

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# Attachment A

## HLW Candidate Performance Based Incentive - FY99

**PBI Title:** New Technology Applications for Waste Retrieval

**DOE SR Manager:** Roy J. Schepens

**WSRC Manager:** Austin Scott

| | |
|---|---|
| Initiate Tank 19 Heel Removal: | $400K |
| Complete Tank 19 Heel Removal: | $350K |
| Complete 1F Evaporator Sampling: | $250K |

**Maximum Fee Available:** $1,000,000

**Description of Work:** Removal of waste heel from Tank 19 to render this tank in a condition ready for closure (i.e., no further waste removal required for closure of the tank) using new technologies developed for this application. Complete sampling of the 1F Evaporator in support of closure module preparation.

**Goal/Objective:** The successful deployment of new technologies for retrieval of waste heel from HLW Tank 19 is expected to lead to application of these technologies to accelerate waste retrieval and closure activities for other HLW tanks and facilities and to foster a positive attitude towards the consideration of new "better, faster, cheaper" solutions to achieve HLW program objectives. Funding to support the development of the technologies to be applied under this PBI has been provided by the EM-50 Tanks Focus Area. Successful deployment of these technologies will result in reduced cleanup costs and strengthen the relationship with EM-50 and other DOE sites. Completion of sampling activities for the 1F Evaporator constitutes a significant step towards identifying the final scope of work associated with closure of this facility and supports long-term site commitments to close out-of-service HLW tanks and facilities.

**Fee Schedule Levels:**

Initiation of waste heel retrieval activities (actual transfer of waste out of tank) in Tank 19 by 7/31/99 for a fee of $400,000.

Completion of all waste heel retrieval activities on Tank 19 such that the tank is in a state of readiness for closure with no further waste retrieval actions required by 9/30/99 for an additional fee of $350,000.

Complete all sampling (sampling plan developed and agreed to by DOE and samples drawn) required to support the planning and preparation of the 1F Evaporator closure module by 3/1/99 for a fee of $250,000.

Roy J. Schepens
Acting Assistant Manager
High Level Waste, SR

Austin B. Scott, Jr.
Vice President and General Manager
High Level Waste Management, WSRC

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# Attachment B

## Phase I Selection Matrix

### Bulk Heel Removal

| | | Selection Criteria | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cost | Schedule* | Testing | Infra-structure | RadCon | D'stream Impacts | Effect Key Resources | Prob. Of Success* | Reliability | Maturity | Score |
| | | 1.25 | 1.5 | 1 | 1.25 | 1.25 | 1.25 | 1 | 1.5 | 1.25 | 1 | |
| Arm Based | EMMA | | | | | | | | 1 | | | |
| | Delphinus | | | | | | | | 1 | | | |
| | LDUA | | | | | | | | 1 | | | |
| | MDUA | | | | | | | | 1 | | | |
| | Borehole Miner | | | | | | | | 1 | | | |
| Robotic | Track Pump Service Contract | 3.5 | 4.2 | 5 | 4.5 | 4 | 4 | 4 | 4 | 4.2 | 4.25 | 50.80 |
| | ARD Service Contract | 3.5 | 4.5 | 5 | 4.5 | 4 | 4 | 4 | 4 | 4.3 | 4 | 51.13 |
| | SRS Crawler w/Monitors or Brush | 4 | 1.8 | 3.9 | 4.5 | 3 | 3.5 | 3.5 | 2 | 3.3 | 2.5 | 38.48 |
| | SRS Crawler w/Water Mouse | 4 | 1.8 | 3.9 | 4.5 | 3 | 3.5 | 3.5 | 2 | 2.8 | 3 | 38.35 |
| | SRS Crawler w/Pump | 3 | 2.3 | 3.4 | 4.5 | 3 | 4 | 3.5 | 2 | 3.3 | 2.5 | 38.10 |
| | Red Zone Houdini | 1 | 2.5 | 3.4 | 4.5 | 3 | 4 | 3.5 | 3 | 3 | 4 | 38.53 |
| Mixers | 15 hp Stationary Flygts (baseline) | | | | | | | | 1 | | | |
| | 50 hp Stationary Flygts | 3.25 | 5 | 4.3 | 4.5 | 4 | 4 | 3.5 | 2 | 3.6 | 3.5 | 45.99 |
| | 50 hp Rotating Flygts | 4 | 4.75 | 4 | 4.5 | 4 | 4 | 3.5 | 4.5 | 4.2 | 3.5 | 50.75 |
| | Refit Bingham Slurry Pumps | 1.8 | 2.1 | 2.3 | 3 | 2.75 | 4 | 1.75 | 1.5 | 3.5 | 4 | 32.26 |
| | New Lawrence Slurry Pumps | 1 | 2.1 | 2.3 | 3 | 2.75 | 4 | 1.75 | 1.5 | 4 | 3 | 30.89 |
| | Advanced Design Mixer Pumps | | 1 | | | | | | | | | |
| | Mini Quad-Volute Slurry Pumps | 1 | 1.3 | 2 | 2.5 | 2.75 | 4 | 1.75 | 4 | 3.5 | 2 | 30.89 |
| | AEA Pulse Tube Mixers | | | | | | | | 1 | | | |
| Sluicing | Water Monitors | | | | | | | | 1 | | | |
| Chemical | Chemical Cleaning using Sluicing | 4 | 4.5 | 4 | 4 | 4 | 2 | 3.5 | 3 | 4.5 | 3 | 44.88 |
| | Chemical Cleaning using Mixers | 3.5 | 4 | 4 | 4 | 4 | 1.5 | 2.5 | 3 | 4 | 2.75 | 41.00 |

Notes:

* a score of 1 in either of these columns eliminates the option from further consideration.

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# Phase II Selection Matrix

## Residual Heel Removal

| | | Selection Criteria | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cost | Schedule* | Testing | Infra-structure | RadCon | D'stream Impacts | Effect Key Resources | Prob. Of Success* | Reliability | Maturity | Score |
| | | 1.25 | 1.5 | 1 | 1.25 | 1.25 | 1.25 | 1 | 1.5 | 1.25 | 1 | |
| Arm Based | EMMA | 1.33 | 1.83 | 2.5 | 3.33 | 3 | 4 | 4 | 1.88 | 2.38 | 3 | 32.62 |
| | Delphinus | 2 | 2.67 | 2.5 | 3.33 | 3 | 4 | 4 | 1.88 | 2.67 | 2.83 | 34.91 |
| | LDUA | 1.33 | 1.83 | 2.5 | 3.33 | 3 | 4 | 4 | 1.63 | 2.33 | 2.83 | 32.01 |
| | MDUA | 1.33 | 1.83 | 2.5 | 3.33 | 3 | 4 | 4 | 1.88 | 2.5 | 2.67 | 32.44 |
| | Borehole Miner | 2.67 | 2.75 | 3 | 3.5 | 2.83 | 3.17 | 3.67 | 2 | 3.83 | 3.33 | 37.13 |
| Robotic | Track Pump Service Contract | 3.13 | 3.8 | 5 | 4.75 | 3.75 | 4.25 | 4.25 | 4.38 | 4.05 | 4.25 | 50.68 |
| | ARD Service Contract | 3.13 | 4 | 5 | 4.63 | 3.63 | 4.25 | 4.25 | 4.5 | 4.2 | 4.5 | 51.30 |
| | SRS Crawler w/Monitors or Brush | 4.38 | 3.45 | 3.73 | 4.38 | 3.38 | 3.63 | 3.5 | 3.5 | 3.45 | 2.83 | 44.51 |
| | SRS Crawler w/Water Mouse | 4.38 | 3.33 | 3.73 | 4.25 | 3.38 | 3.63 | 3.5 | 3.5 | 3.05 | 3.17 | 44.01 |
| | SRS Crawler w/Pump | 3.88 | 3.33 | 3.35 | 4.5 | 3.38 | 4 | 3.25 | 3.38 | 3.33 | 2.67 | 43.20 |
| | Red Zone Houdini | 1.25 | 3.13 | 3.6 | 4.63 | 3.5 | 4.13 | 3.88 | 3.88 | 3.13 | 3.83 | 42.63 |
| Mixers | 15 hp Stationary Flygts (baseline) | na | na | na | na | na | na | na | na | na | na | na |
| | 50 hp Stationary Flygts | na | na | na | na | na | na | na | na | na | na | na |
| | 50 hp Rotating Flygts | na | na | na | na | na | na | na | na | na | na | na |
| | Refit Bingham Slurry Pumps | na | na | na | na | na | na | na | na | na | na | na |
| | New Lawrence Slurry Pumps | na | na | na | na | na | na | na | na | na | na | na |
| | Advanced Design Mixer Pumps | na | na | na | na | na | na | na | na | na | na | na |
| | Mini Quad-Volute Slurry Pumps | na | na | na | na | na | na | na | na | na | na | na |
| | AEA Pulse Tube Mixers | na | na | na | na | na | na | na | na | na | na | na |
| Sluicing | Water Monitors | 5 | 3.25 | 4.5 | 3.75 | 3.83 | 3 | 3.75 | 2.33 | 4.33 | 3.83 | 45.34 |
| Chemical | Acid/Caustic Sluiced In | 3.83 | 4.17 | 2.75 | 3.5 | 3.88 | 1.75 | 3 | 3.75 | 4.33 | 3 | 42.24 |
| | Acid/Caustic Mixed In | 3.83 | 4.17 | 2.75 | 4 | 3.88 | 1.5 | 3.13 | 4 | 4.33 | 3 | 43.06 |

Notes:

[1] "*" indicates a score of 1 in either of these columns eliminates the option from further consideration.

[2] na - the best of these options was selected fo Phase I

[3] inputs from T. Hess, P. Rodwell, E,. Howard and N. Davis



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