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Robotic Removal of Zebra Mussel Accumulations in a Nuclear Power Plant Screenhouse

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ABSTRACT

Zebra mussel accumulations in the power plant intake system have increased over the last four years and have become a maintenance issue. Several treatment methods have been used in combination, including molluscicides, chlorination and mechanical cleaning by divers.

Mechanical cleaning by divers is limited to areas of relatively low flow velocity. Various sections of the screenhouse are not accessible except during an outage or when one of the intake tunnels can be otherwise be blocked and flow reduced. In addition, diver services are relatively costly. For the above reasons, the Indiana Michigan Power Co., Cook Nuclear Plant, contracted with ARD Environmental Inc. to develop and test a robotic system as an alternative to cleaning by divers.

The first phase of this project addressed the requirement to clean the screenhouse floor in all areas, including those with high flow velocity. Subsequent phases will address robotic cleaning of other areas of the intake and the screenhouse structures.

The objectives of the project were to:

1) Demonstrate the ability to deploy and retrieve a modified XT1000 vehicle in the inlet bay and screen bays.

2) Remove the accumulations of zebra mussels and possibly other pumpable material from the floor.

3) Reduce or eliminate the need for diver services and reduce overall cost of removing accumulations of zebra mussels.

4) Critique operations and develop recommendations for further enhancements to the robotic equipment and materials handling system.

Implementation of the operating plan commenced on September 8,1994, and was completed on October 7, 1994. The project demonstrated that robotic techniques are an efficient and cost effective alternative to diver operations for mechanical removal of zebra mussels. In particular, the robotic system was able to operate effectively in the high flow velocity areas including those at the intake tunnels. The ability to operate in the high flow areas means that zebra mussel removal may take place at any time, without affecting normal plant operations.

INTRODUCTION

Initial discussions were held with Cook Nuclear Plant personnel in mid-July 1994. The purpose of these discussions was to define to project requirements, and discuss the approach to be taken by ARD Environmental, Inc. (ARDE), in performing the project. Pursuant to these discussions, ARDE prepared an Operating Plan, which described, in detail, the proposed system and equipment, the methods and procedures to be used, plant support requirements, and safety considerations. The Operating Plan also included a detailed project schedule (Figure 1).

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2) Remove the accumulations of zebra mussels and possibly other pumpable material from the floor.

3) Reduce or eliminate the need for diver services and reduce overall cost of removing accumulations of zebra mussels.

4) Critique operations and develop recommendations for further enhancements to the robotic equipment and materials handling system.

The first cleaning effort was performed by ARD Environmental (ARDE) personnel. Subsequent cleanings may also be performed by ARDE personnel, however the overall goal of the project is to develop equipment and a methodology that would permit Cook Nuclear Plant personnel to perform maintenance cleaning and removal of zebra mussel infestations in the inlet bay and semen bays on a routine basis, with minimum support from outside contractors.

This phase of the project consisted of a number of tasks. They included a detailed review of the engineering drawings of the screenhouse, a review of plant operational requirements, design modifications to ARD’s XT1000 vehicle to permit insertion in the manways at the plant, design and fabrication of ancillary equipment to support the operation, and development of an operating plan that meshed with plant requirements and activities during a scheduled outage.

The specific cleaning tasks were to remove zebra mussel accumulations from the floor of the screenhouse, in the areas between the traveling screens and trash racks, and west of the trash racks, in the inlet bay and in the triangular trash traps in the comers of the screenhouse (Figure 3).

Operations were required to be conducted on a non-interference basis with other activities being conducted in and around the screenhouse. These included molluscicide treatment of the South Intake tunnel, diver activities in various portions of the screenhouse, and other activities associated with the Unit 2 outage and general operations in the plant.

The robotic system was able to operate in all conditions encountered, although there are improvements that would be incorporated in a production system. Mounds of mussels 8'-10' in height were encountered and successfully removed. Even where there was a large mound where the vehicle was introduced into the screen bay it was capable of working its way through the mound to the bottom, and then maneuver to remove the remainder of the mound.

The next version of the system will incorporate the lessons learned during this project, both in equipment configuration and operating procedures.

PLANT DESCRIPTION AND OPERATING ENVIRONMENT

The Cook Nuclear Plant is shown in plan view in Figure 2. Cooling water for the plant is brought into the screenhouse through three intake tunnels, 16' in diameter, which extend approximately 2300' into Lake Michigan. The screenhouse is a concrete chamber approximately 200' long by 108' wide by 45' deep. The screenhouse is divided into three major areas: The forebay, which is the area between the intake tunnels and the trash racks; the screen bays which are the areas between the trash racks and the traveling screens; and the pump bay which is the area between the traveling screens and the circulating water pump inlets. There are also two trash traps, which are triangular areas on each end of the forebay isolated by baffle walls. The screenhouse layout is shown in Figure 3.

Zebra mussels accumulate on the inside of the intake tunnels and on the intake tunnel cribs and surrounding rip-rap. Inside the screenhouse, they accumulate on the walls, floors and trash racks, except in areas of high flow. Large piles of mussels, which slough off from other areas, accumulate on the screenhouse floor in areas of low flow, and against out-of-service traveling screens. These piles may reach heights in excess of 10'.

The plant was undergoing an outage, with Unit 2 down for refueling. Four circulating water pumps were shut down for most of the operation reducing flow through the screenhouse by 57%. The Unit 2 traveling screens were also shut down for maintenance. The south intake was closed off by a stop log and was undergoing treatment with molluscicide to kill the mussels lining the intake pipe.

Other operations in the screenhouse included traveling screen maintenance, routine operations, and diver operations to clean the screenhouse walls on both sides of the traveling screens.

Lake Michigan was generally calm, although there was a period of thermal inversion and rougher conditions which significantly reduced visibility in the screenhouse for a period of time. No extreme temperature or other weather conditions were experienced.

EQUIPMENT DESCRIPTION

The overall system is shown in the block diagram in Figure 4. The prototype vehicle consists of a tracked, pneumatically-driven platform based on the ARDE XT1000 A four horsepower air motor and 60:1 gearbox are used to drive each track. The motors and gearboxes are modified for use underwater. The prototype vehicle was reduced in size and otherwise reconfigured to permit entry via the screenhouse access points in the Cook Nuclear Plant. In addition, the side plates were cut down to reduce hydrodynamic drag.

A suction head with raising and lowering capability was mounted on the front of the prototype vehicle, and an underwater camera and light assembly with full pan and tilt, was mounted on a folding pedestal on the port side. This camera permitted the operator to navigate in the screen and inlet bays, and to monitor mussel removal. The vehicle is shown in several views in Figure 5.

The umbilical assembly consisted of four supply and return air lines (two for each motor), four small diameter control tubes to raise and lower the suction head and camera, a high-strength buoyant tether, and the suction line from the pump to the prototype vehicle. In addition, a 2“ closed hose was added to maintain the umbilical positively buoyant.

The handling equipment consisted of three mobile engine-hoist cranes modified to handle the prototype vehicle and associated equipment. One crane was equipped with an electrically-driven capstan and snatch blocks for handling the prototype vehicle. The second and third cranes were identically equipped with electric winches and snatch blocks to handle the auxiliary camera and to suspend the diver’s submersible pump. Aluminum channels were used to span the manways and grates, permitting safe positioning of the cranes over the openings.

The auxiliary camera assembly consisted of a 2’ square cage equipped with upper and lower rollers on the back side. An underwater camera, lights and pan and tilt unit was mounted on a plate on the bottom of the cage. The vehicle camera was a color unit, and the auxiliary camera was a black-and-white low light level unit. The purpose of the auxiliary camera was to provide the operator with a means of observing insertion of the prototype vehicle. After the first deployment, the auxiliary camera was considered unnecessary and was not used thereafter.

The operator console consisted of a portable cabinet in which were mounted video monitors, pan and tilt control units, and VCRs for the vehicle and auxiliary cameras. An audio recorder was also installed to permit logging of commentary by the operator. High noise environment sound-powered phones were included to permit communications between the two operators.

The vehicle control console was a separate portable unit, normally used with the XT10000 vehicle, to permit the operator freedom of movement. This was found to be unnecessary for this operation, and the portable console was eventually mounted in front of the video monitors. All pneumatic control valves are electrically operated via the joysticks on the vehicle control console. The pneumatic control assembly contains all of the pneumatic valves, pressure regulators, and exhaust mufflers for the subsystem.

Initially per a request from Cook Nuclear Plant personnel, ARDE used a pump supplied by the divers. This pump was a 4 electrically-powered ABS submersible. Difficulty in priming and lack of sufficient 440 volt outlets required changing the pump. ARDE then rented a 6" diesel-powered Godwin self-priming pump for the remainder of the project.

OPERATIONS

Mobilization commenced on 9/8/94. Training and badging had been conducted previously at the plant, therefore no delays were experienced once ARDE staff arrived at the site. The equipment was unloaded and set up on 9/12 and 9/13, and operations commenced on 9/ 14, in accordance with the schedule in ARDE's Operating Plan.

All equipment with the exception of the air compressor and Godwin pump were located inside. The compressor and pump were placed against the west wall of the screenhouse, in temporary containments in the event of fuel spills. ARDE's truck was also parked outside the screenhouse.

Occasional delays were experienced during the project due to other, higher priority, activities associated with the outage. Some delays were also experienced when the divers were unable to retrieve their pump on request, due to other activities. These delays reduced the overall effectiveness of ARDE's operation in terms of total time on site versus total volume of mussels pumped. This would not be an issue for a future production system operated by plant personnel.

The Operating Plan initially addressed cleaning of all areas of the screen and inlet bays. Based on prior diver reconnaissance, the plan was modified and only selected areas, with significant accumulation of mussels, were entered and cleaned. Table 1 summarizes performance in each area.

No safety or health incidents occurred during the operation, and no support was required from the divers or plant personnel, once the diver's pump was replaced. Operations were completed on 10/6/94, and the equipment was broken down and removed on 10/7, approximately 10 days ahead of the original schedule.

The Operating Plan described several techniques to be used for entering the various areas in the screen and inlet bays. In practice these methods were simplified considerably. Some of the equipment prepared for the project, such as the crane for the pump, was not required. Appendix (A) contains various photographs, taken during the project, showing the equipment and conditions in the screenhouse.

System Performance

Performance of the ARDE system was equivalent to diver performance when equivalent conditions existed. That is, where large mounds of mussels were encountered, and pumping capacity was the same, the rate at which mussels could be removed was equal to diver performance. Although clogging and inability to prime were problems encountered with the ABS submersible electric pump, when it operated properly it was very effective.

The centrifugal trash pump substituted by ARDE was at a disadvantage as it had to overcome a static suction head of about 16'. On the other hand, clogs could easily be cleared by injecting either air or water into the suction hose. Any future system would utilize a hydraulically-driven submersible pump. This would permit clearing of clogs by reversing the pump, as well as water or air injection. Moreover the advantage of reduced total equivalent head would be recovered.

Table 1 lists the area worked, pumping hours, total volume and pumping rate. The forebay areas are west of the trash racks, and the screen bay areas are west of the traveling screens. A memo with additional information and comments is included in the appendix. The bare numbers below do not reflect the advantages that a production system would enjoy which include: Operation at any time and shift; operation in or transit of high flow areas; no confined space entry or other major safety related requirements; cleaning of screen bays with traveling screens in operation; and operation independent of plant status.

Note that the dumpsters used had a maximum capacity of about 24 cubic yards. Since the gravity drain reduced the usable overall height, the dumpsters were only filled to about 80% of maximum capacity (about 20 cubic yards), to permit them to be tilted without spillage during removal.

Adversity Factors

ABS Submersible Pump

Although the ABS pump supplied by the divers had a high delivery rate, it was not the best choice for several reasons.

- Installing or removing the pump required the services of the divers, since it was their pump.

- The pump was electrically-driven by a 440 VAC 3-phase motor, thus it was not reversible, which made it more difficult to clear clogs.
- There was no provision for back flushing either with air or water, which also made it more difficult to clear clogs.
- Clearing a clog required the pump to be pulled from the water and the suction line (and possibly the discharge line) disconnected.
- This type of pump is not capable of clearing air from a loop in the suction line, making start up more difficult.

Visibility

Poor visibility, caused by thermal inversion in the Fall and Spring or storms at any time, prevent the use of the prototype vehicle as it is presently configured. Visibility varied from 10 to 15 feet in clear conditions to less than 1 foot in poor conditions. Poor visibility would also hamper a diver if he had to locate a pile of mussels. However, if he knew where the mussels were, an experienced diver could readily locate and remove them by feel.

Even under ideal conditions, visibility is limited in the large open areas of the inlet bay. This limits direct point-to-point navigation in these areas. However, it does not prevent use of the vehicle as the mussels accumulate against the walls, and the vehicle can always be directed along a wall.

ARDE intends to test an ultrasonic imaging system to determine if this would be a useful adjunct to the video system. Note that although the vehicle is hampered by poor visibility at present, it can be used whenever convenient, thus times of poor visibility can be avoided. Note also, that only about 2 days of operation were affected by poor visibility.

High Flow Conditions

The prototype vehicle was operable in all locations, however the effects of high currents were definitely felt in several areas.

After initial entry into the traveling screen area of Unit 2, which was in a refueling outage, the vehicle was deployed into a number of high flow areas on the operating unit 1 side of the screenhouse to both remove material and demonstrate the ability of the system to be deployed and operate in these areas.

The first high flow deployment was in the forebay area directly across from the center intake. The deployment, initiated from behind the baffle wall, was successful. After removing the accumulations of materials from that area the vehicle was moved around the corner and toward the intake tunnel. After rounding the baffle the vehicle was oriented to face the inlet directly using the baffle wall as a reference. The vehicle was then driven toward the intake. The actual vehicle path was a slow arc toward the north end of the forebay due to the effects of the flow on the discharge and control hoses.

After orienting the vehicle again, a second, successful, attempt was made to reach the intake. As the vehicle approached the intake, flow velocities increased dramatically. The ability of the vehicle to turn and move decreased, as well as the ability of the operator to accurately determine the location of the vehicle, its proximity to structures, and its orientation within the forebay.

Conflicting Operations
Other priority operations, related to management of outage-related activities, resulted in some delays to ARD's activities. Early in the project, when diver support was required to move their pump, some delays were experienced because dive personnel were not always available. A production system, operable by plant personnel at convenient times, would not experience these delays.

Dumpster Configuration
The dumpsters used were standard 20’x8’x4’ units with swing-open doors. The dumpsters are designed to handle solid waste material. Each time the dumpster is removed from the site and emptied it must be resealed to provide a proper waterproof seal. This requires approximately 12 tubes of silicone caulk and 30 to 45 minutes of time. The seals achieved by this method are marginal in their ability to keep water from leaking onto the ground.

The current method of material dewatering utilizes a single or dual 8“ gravity decant. This system provides adequate flow volume to keep the water level inside of the dumpster. There are a number of disadvantages to this particular system. The 8“ decant lines are bulky and difficult to manage when full of water. The final decant of free water following filling of the dumpster is a slow process. A 2“ clear tube is used as a siphon which takes approximately 1 hour to finish the decant to a level acceptable for transportation.

Piping and Dumpster Layout
Although there was enough space to lay out all the umbilicals and discharge lines, the presence of other equipment, and other activities made umbilical handling more time consuming and difficult. The placement of the dumpsters required the discharge hose to be disconnected and moved whenever dumpsters were brought in, or other equipment required access to the area.

Umbilical/Discharge Hose Weight
The weight of the hose/umbilical assembly made it difficult for two men to retrieve the system. Retrieval had to stop periodically so the hose/umbilical could be rearranged.

Equipment Malfunctions
Only two malfunctions were experienced during the operation. The first was the inability to lower the vehicle camera for vehicle retrieval. This was traced to a faulty air line connection which most likely occurred during assembly of the system. The air line feeding the retract side of the camera air cylinder was not fully seated in the connector. During operation, the air line pulled loose, preventing the cylinder from lowering the camera. The vehicle was raised as high as possible, and the line was connected by reaching into the manway.

The second malfunction was caused by leaking seals on the camera cylinder. The cylinders installed initially on the camera and suction head were not rated for underwater use. However, because of schedule, and the long lead time for rated cylinders, a decision was made to use off-the-shelf unrated units, and the underwater rated units were ordered at the same time. When the seals started to fail on the camera cylinder, the rated replacements were shipped and arrived the same day. It was installed the next morning with very little loss of operational time.

OBSERVATIONS AND LESSONS LEARNED

A) Mussels continue to accumulate in stagnant areas immediately after they have been cleaned. For any given set of flow conditions these areas are well defined.

B) Accumulations at the base of the traveling screens can be caused by cleaning operations with the screens secured. Restarting the screens can result in significant carry-over of mussels, therefore the screens should be operated continuously while cleaning operations take place.

C) The trash racks tend to accumulate significant growth of mussels about halfway down, yet appear to be clear near the surface and the bottom. This is probably attributable to the vertical flow velocity profile. If necessary the trash racks could be cleaned from the surface.

D) Routine cleaning of areas where large accumulations occur, particularly in the screen bays, would be effective in preventing carry-over and clogged traveling screens.

E) Operations could be made more efficient if the removal process were treated as routine maintenance, rather than a periodic problem to be solved.

F) Increasing vehicle weight, and modifying the attachment points for the umbilical and suction hose would improve handling in high flow areas. A flexible attachment point, which would allow the suction hose and umbilical to swivel around two axes would enable the vehicle to maneuver more freely as the suction hose and umbilical would be better able to align with the flow, regardless of the direction of motion of the vehicle.

G) Improved articulation of the suction head would allow the vehicle to drive straight into the piles of mussels and other debris.

H) Track redesign would aid in deployment by allowing the tracks to come into contact with the screenhouse floor with the vehicle in the vertical position.

I) The temporary and expedient nature of the shell removal piping dumpster configuration, dumpster decant system, and dumpster staging slowed the overall removal rate of the mussels.

With the above improvements, the robotic system represents a cost-effective alternative to the use of divers for screen and inlet bay floors.

RECOMMENDATIONS

The complexity of the zebra mussel problem, coupled with the complexity of power plant operation, suggests that an analysis be done to determine the optimum, cost-effective solution to the problem. It is clear that a combination of techniques are required, each to address a specific problem area. The ongoing nature of the problem suggests that some permanent installations are required, for example, piping and manifolds to carry the mussels to the container site.

Improvements to the vehicle would include reducing its width to permit the vehicle to access the trash traps via the 24’’x 24" openings, increasing vehicle weight and modifying the suction hose attachment point to reduce the effects of hydrodynamic drag on vehicle maneuverability. In addition, the pneumatic drive and actuation cylinders would be replaced by hydraulics, and the track profile would be modified to permit easier insertion of the vehicle. Articulation of the suction head would permit the vehicle to be driven straight into the piles of mussels.

Optimizing the equipment operationally would also require a purpose-designed handling system, controllable locally or from the operator’s console. The handling system would incorporate power-assist for the umbilical, as well as an improved vehicle winch.

Since zebra mussel removal appears to be a long-term problem, operations in general would be simplified by installing a permanent piping and manifold system in the screenhouse for the pump discharge. Permanent outside piping, and a more convenient site for the dumpsters used to haul the mussels, would also facilitate operations, as would substitution of a decant pump for the gravity decant method currently in use.

COMPARISON OF VEHICLE AND DIVER OPERATIONS

Diver operations and the use of the robotic system were compared for cost and efficiency, and each technique has its merits. Based on experience at the Cook Nuclear Plant, the crew size needed to operate the robotic system under various scenarios, as follows:

Case A: Robotic system operated by contract diving personnel

One diver/ vehicle operator
Two tenders/ laborers

Case B: Robotic system operated by newly trained in-house personnel with contract labor support

Two maintenance mechanics/ operators
Two laborers

Case C: Robotic system operated by experienced in-house personnel with contract labor support

Two maintenance mechanics /operators
One laborer

Case D: Optimized Robotic system operated by experienced in-house personnel with contract labor support

One maintenance mechanics/ operator
One laborer

Case E: Diver removal of mussels by conventional pumping

One diver/ supervisor
One diver
One tender
One laborer

Table 2 is a qualitative pro/ con comparison of the techniques.

CONCLUSIONS

The project goals for this phase were met. The ARDE Robotic system can provide a cost-effective alternative to diver operations for removal of zebra mussels from the screenhouse floor at the Cook Nuclear Plant. The prototype system, a modified ARDE XT1000, incorporating special features for the project, demonstrated the feasibility of the approach.

The experience gained on the project will enable a production system to be designed and built that will meet ongoing needs of the plant on a routine basis. For optimum operational efficiency, some piping and a dedicated hydraulic power unit should be permanently installed in the plant. In addition, the dumpsters and decanting method should be replaced with a more suitable approach.

While divers can be replaced for cleaning the screenhouse floor, they are still needed to clean the walls, and to perform other activities in the plant.

ACKNOWLEDGEMENTS

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Table 1. Performance Summary

AREA WORKED	PUMP HOURS	TOTAL VOLUME CU YDS	PUMPING RATE YDS/HR
2-6,7	3	12	4
2-6,7	3.5	8	2.3
2-2,3	1	2	2
2-2,3	4	8	2
Unit 2 Forebay	2	2	1
Unit 1 Forebay	2.5	5	2
Unit 1 Forebay	2	6	3
1-4,3	2	5	2.5
1-4,3	2	3	1.5
1-4,3	3.5	9	2.6
1-4,3	3.5	7	2
1-2,1	3.5	7	2
1-2,1	3	6	2

Table 2 Comparison of Cleaning Techniques

TECHNIQUE	PRO	CON
DIVING	WIDE CHOICE OF TOOLS / MOST FLEXIBLE	LARGER CREW SIZE
	CLEAN FLOOR OR WALLS	NUMEROUS SAFETY ISSUES
	CAN OPERATE IN POOR VISIBILITY	SECOND DIVER MUST BE READY TO ASSIST IN CASE OF EMERGENCY
		LIMITED ENDURANCE
		CANT WORK IN HIGH FLOW
		MUST SECURE TRAVELING SCREENS FOR SAFETY
		BACKUP SYSTEMS REQUIRED
ARDE ROBOT	SMALLER CREW SIZE	LIMITED CHOICE OF TOOLS / NOT AS FLEXIBLE
	FEW SAFETY ISSUES	CLEAN FLOOR ONLY
	UNLIMITED ENDURANCE	POSSIBLY LIMITED BY POOR VISIBILITY
	TRAVELING SCREENS CONTINUE TO OPERATE	MAY REQUIRE DIVER RETRIEVAL IN CASE OF MALFUNCTION
	CAN WORK IN HIGH FLOW	
	EQUIPMENT CAN BE LEFT SUBMERGED INDEFINITELY	
	BACKUP SYSTEMS NOT REQUIRED	

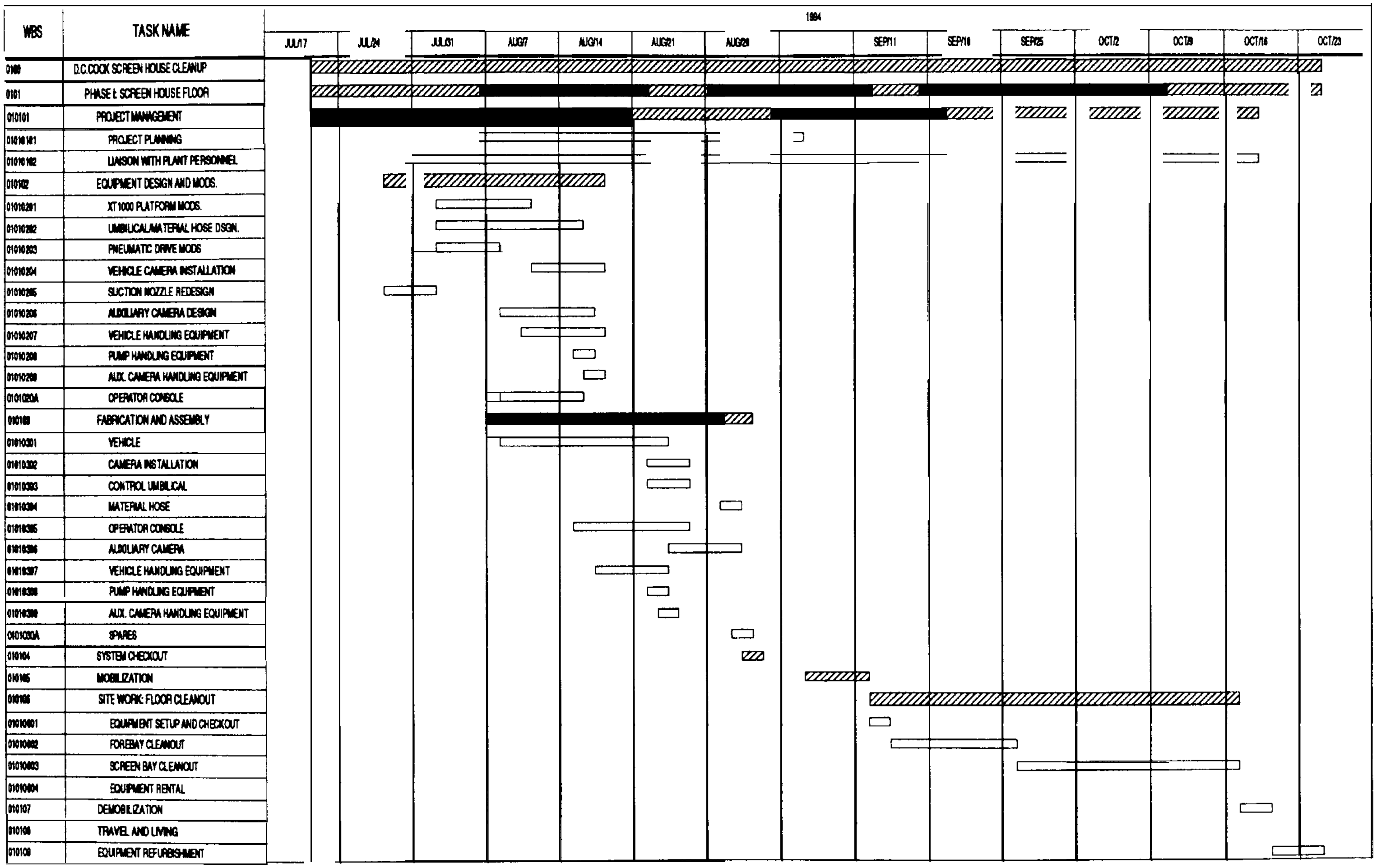

Figure 1. D.C. Cook Phase I: Screenhouse Floor Cleaning Project Schedule

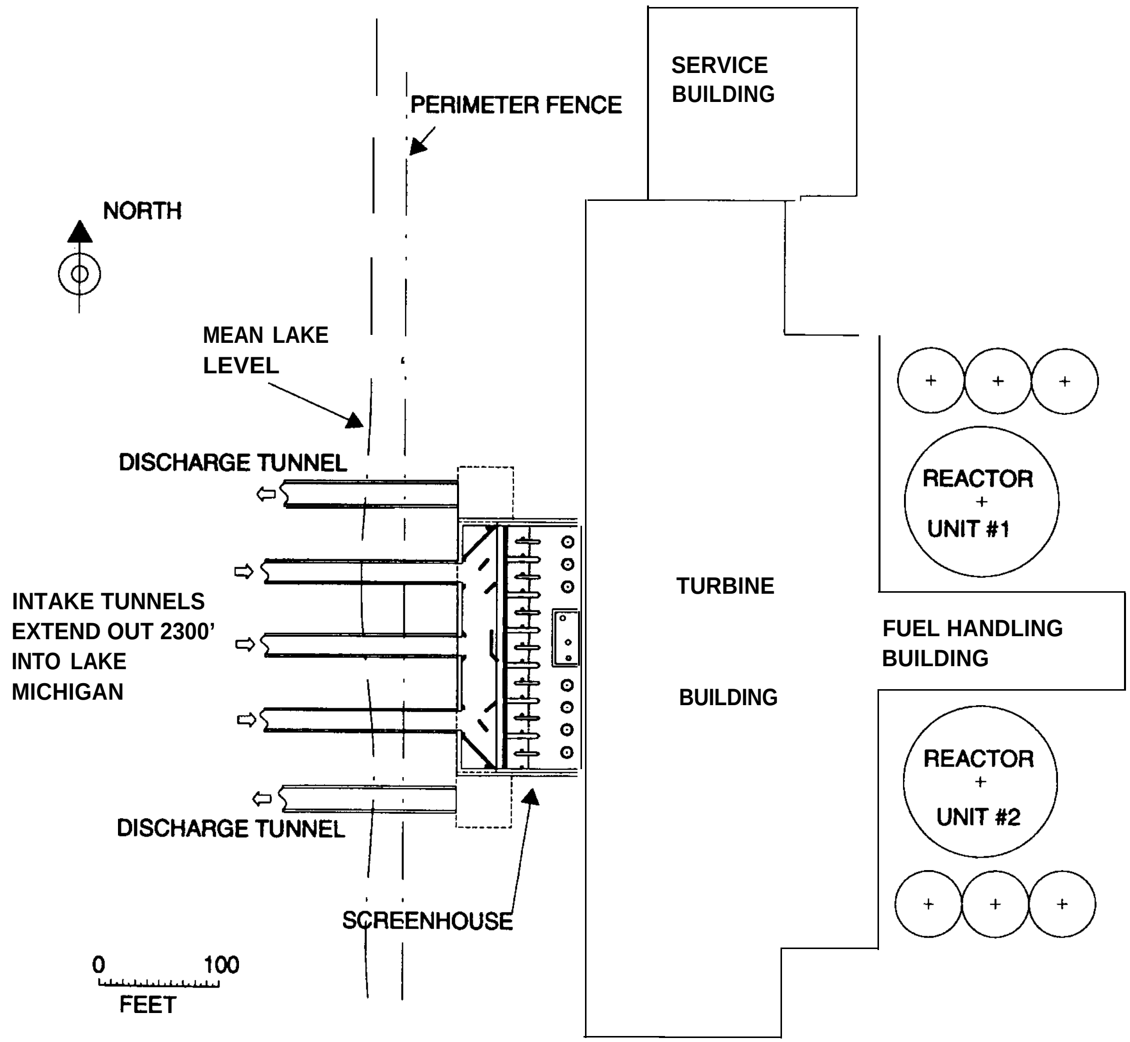

Figure 2. Cook Nuclear Plant

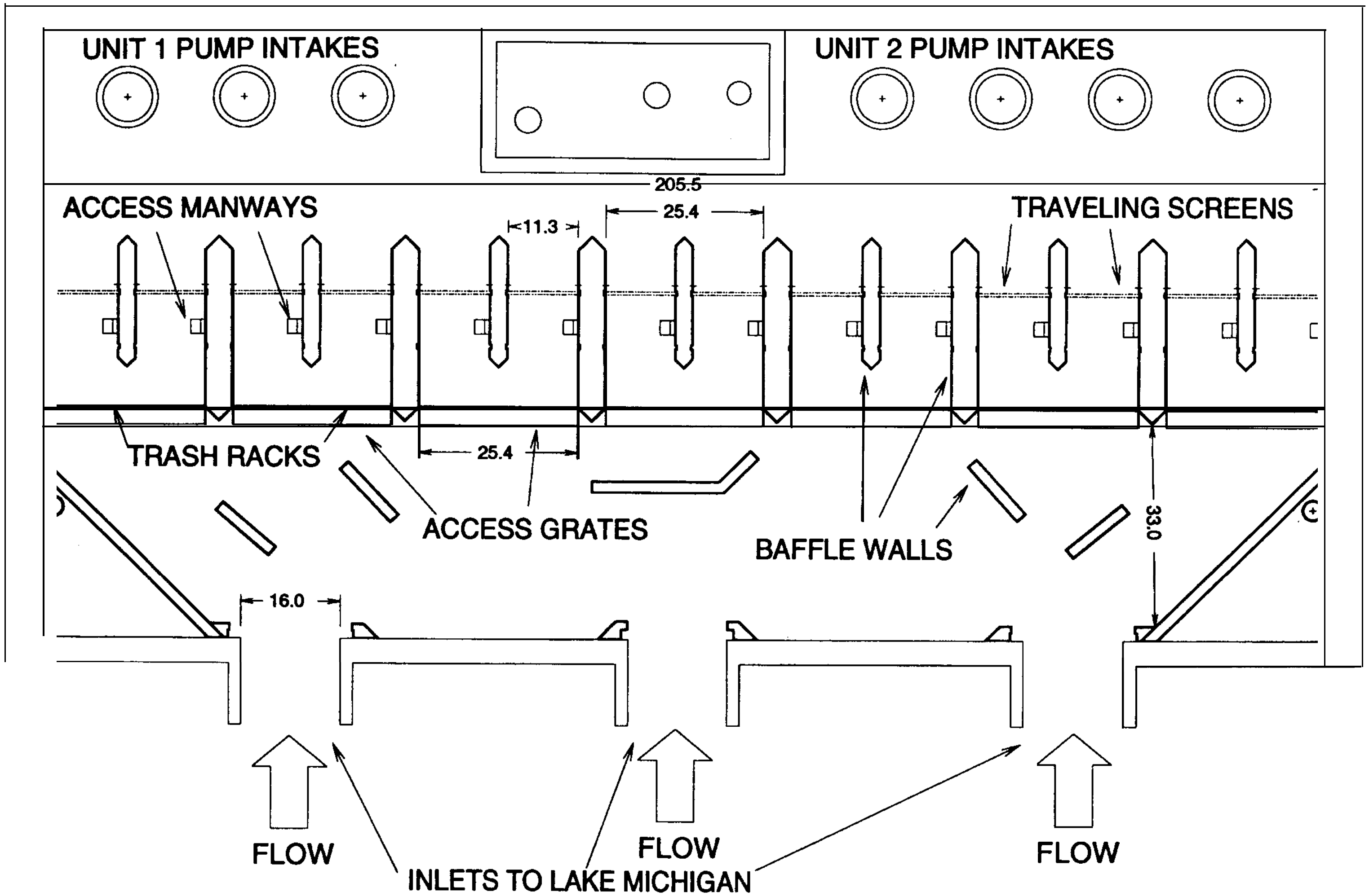

Figure 3. Screenhouse Layout, Cook Nuclear Plant

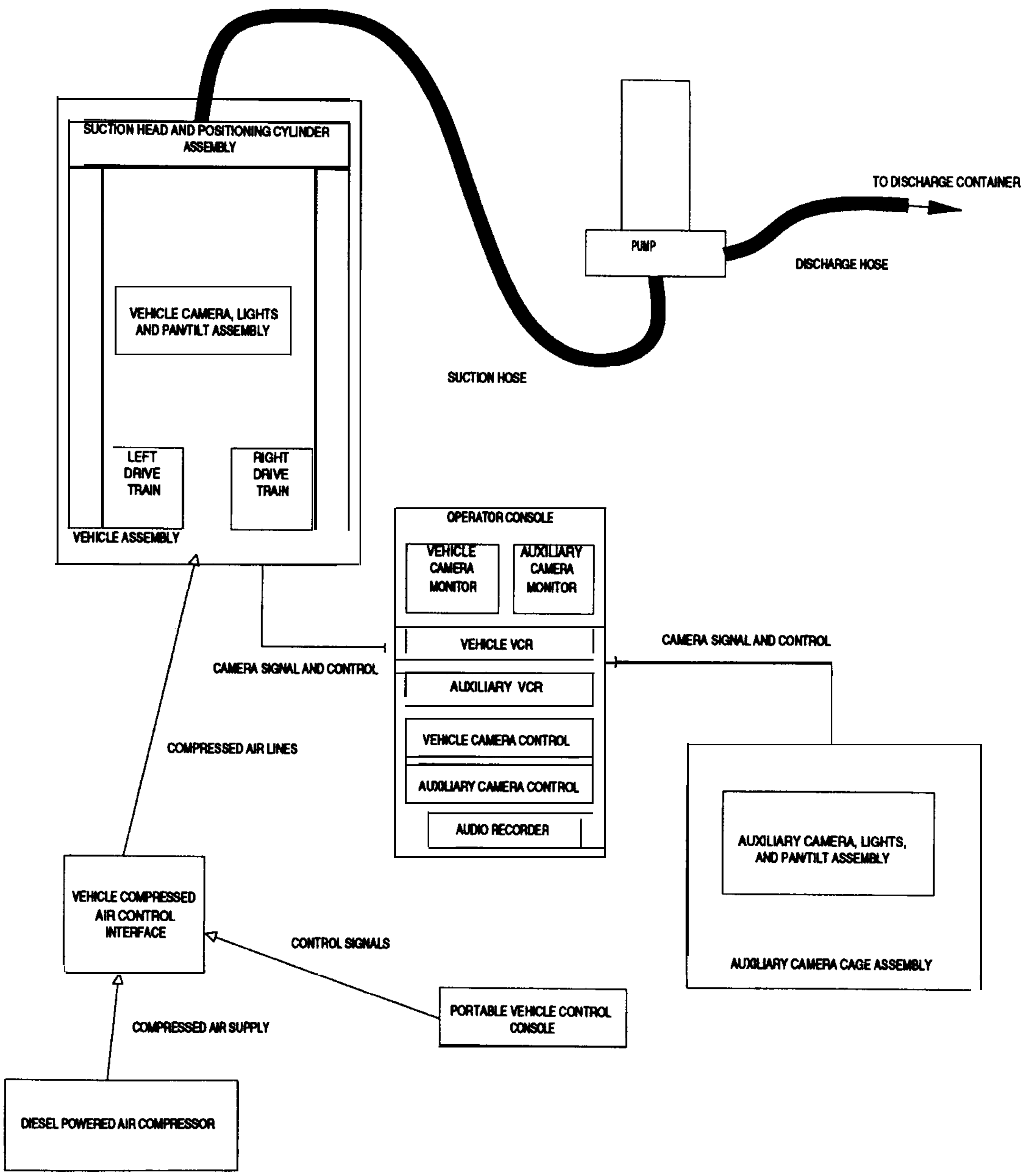

Figure 4. System Block Diagram, Zebra Mussel Removal Equipment, Cook Nuclear Plant

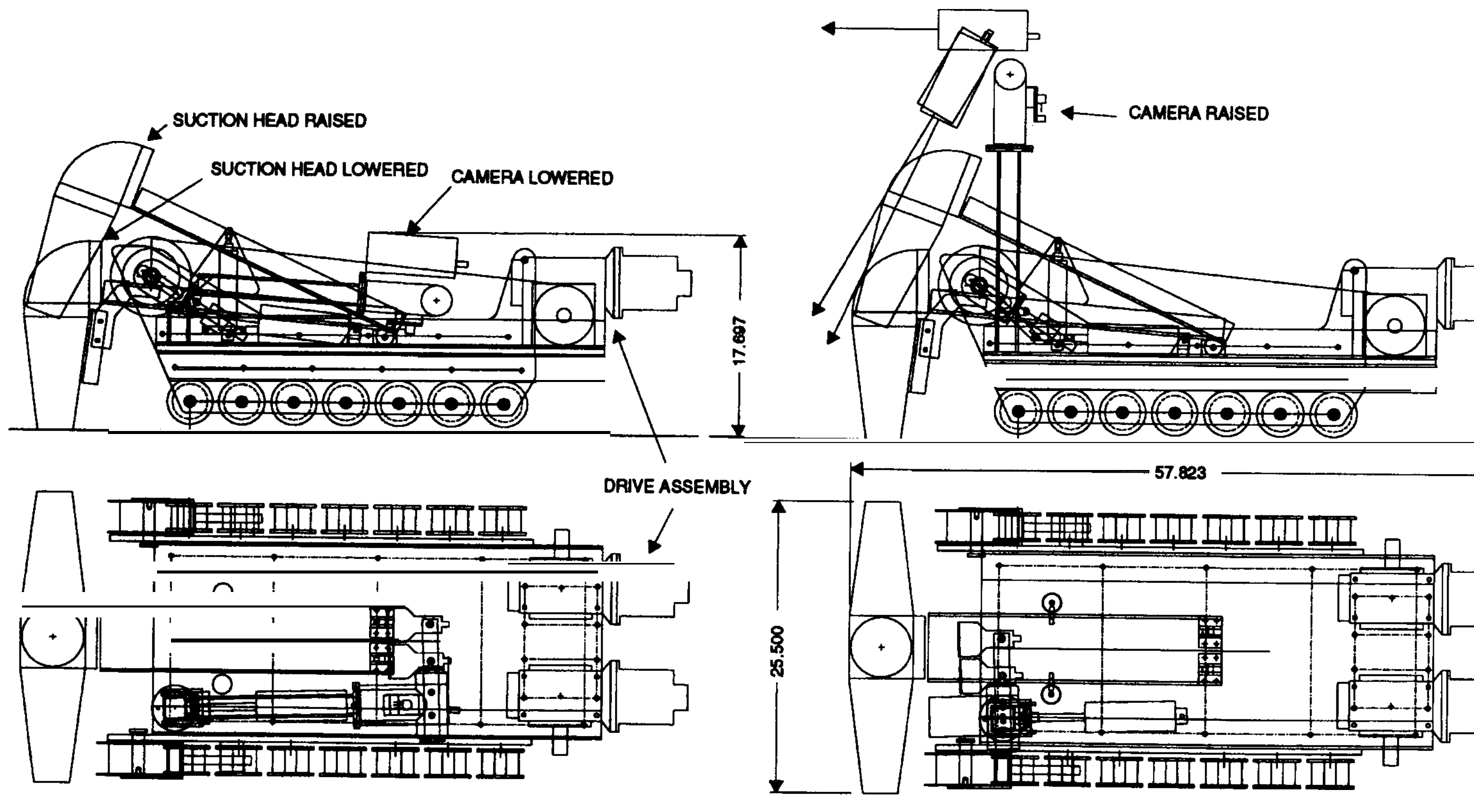

Figure 5. Modified XT1000 for Zebra Mussel Removal Project