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BOA: PIPE-ASBESTOS INSULATION REMOVAL ROBOT SYSTEM

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DISCLAIMER

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Pipe-Asbestos Insulation Removal Robot System

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I. ABSTRACT

This paper describes the *BOA* system, a mobile pipe-external crawler used to remotely strip and bag (possibly contaminated) asbestos-containing lagging and insulation materials (ACLIM) from various diameter pipes in (primarily) industrial installations across the DOE weapons complex. The mechanical removal of ACLIM is very cost-effective due to the relatively low productivity and high cost involved in human removal scenarios. *BOA,* a mechanical system capable of removing most forms of lagging (paper, plaster, aluminum sheet, clamps, screws and chicken-wire), and insulation (paper, tar, asbestos fiber, mag-block) uses a circular cutter and compression paddles to cut and strip the insulation off the pipe through compression, while a HEPA-filter and encapsulant system maintain a certifiable vacuum and moisture content inside the system and on the pipe, respectively. The crawler system has been built and is currently undergoing testing. Key design parameters and performance parameters are developed and used in performance testing. Since the current system is a testbed, we also discuss future enhancements and outline two deployment scenarios (robotic and manual) for the final system to be designed and completed by the end of FY'95. An on-site demonstration is currently planned for Fernald in Ohio and Oak Ridge in Tennessee.

II. INTRODUCTION

Asbestos insulation abatement has, and still is, a big problem in renovation and dismantlement [3], since EPA and OSHA regulations are strict on removal procedures and worker safety [4], due to the carcinogenic nature of the insulation product (despite ongoing disputes) [5].

The Department of Energy (DOE) owns many chemical processing plants across the US, which are scheduled for dismantlement. Most of their steam and process lines have been insulated with ACLIM and hence warrant special attention, especially due to the high potential of contamination with contaminated fluids and particles. Hence, these lines within the DOE weapons complex warrant the use of a mechanical and remote device due to the high costs of abatement, making manual removal and disposal extremely costly and highly inefficient.

III. PROBLEM STATEMENT

The biggest challenges for the design of the machine hinged on the process, facility and regulatory constraints we developed during the design phase. The concerns in each topical area are discussed in more detail below:

- **Process**
  Determining the proper cutting and removal tools and methods to remove all forms of lagging and insulation prevalent in the facilities was the biggest challenge. In addition, handling the removed insulation and bagging it will be of importance in order to develop a fully capable and self-sustained system.
- **Facility**
  The facility constraints drove us to focus on pipe-size ranges of 4 to 8 inch nominal pipe diameter, since they were fairly accessible and represented a large amount of linear footage across the DOE complex. In addition many obstacles had to be negotiated such as hangers, valves, junctions, bends and even neighboring pipe runs.
- **Regulatory**
  EPA and OSHA regulations require that the fiber-count not exceed a certain amount over a typical 8-hour work-period. The tightest regulation we are aware of is about 0.1 fibers per cubic centimeter over an 8-hour period. Requirements for HEPA filters and encapsulation agents had thus to be adhered to.

All of these criteria, whose details are much too lengthy to be listed here, were used to develop the eventual design which is presented in the next section.

IV. SYSTEM SPECIFICATIONS

The overall system performance specifications that we developed as part of our fact-finding missions [1],[2] can be summarized as follows:

4.1 Mechanical

The specifications for the crawler robot are summarized in several key criteria as shown below:

- **Pipe Size** (nom. O.D. [in]) .... 4 - 8
- **Insulation Thickness** [in] .... 1 - 2
- **Lagging**....Paint/Plaster, Chicken-wire, Aluminum Sheet, Clamp/Screw
- **Insulation Types** .... Powder to Mag-block
- **Wetting/Encapsulation**... YES
- **Fiber Flyings Reduction** .... Vacuum/Air Flow
- **Profile** (x-section) .... MIN
- **Body** (obstacle avoidance)............................... Orientable
- **L&I Packaging** .... Yes, all orientations
- **Weight** [lbs] .... MIN
- **Supplies**Hydraulics, Electric, Air, Encapsulant, Poly-bags
- **L&I Bagging** .... 6-mil poly-bags; continuous stream
- **Adaptability** .... Self-adapting or reconfigurable
- **Waste Stream** .... Mixed ACM & Lagging
- **Cleanup** .... Wash-down or Immersion

4.2 Operations

The operational specifications for the *BOA* system are summarized as follows:

- **Applicability** .... Anywhere and self-starting
- **Deployment**....................................... Manual and Remote
- **Exceptions**.................. Hangers, valves, bends, junctions
- **Containment** .... No enclosures
- **Manual Touch-up**....................... +/- 6" around obstacles
- **L&I Removal Speed**.................................. 2 to 8 feet/hr.
- **Operational Mode** .... Manual & Automatic

4.3 Regulatory

The regulatory requirements for the robot system are as follows:

- **Fiber Emissions** .... according to EPA & OSHA & Contractor
- **Wetting** .... Yes, internally
- **Encapsulation** .... Yes
- **Air Monitoring** .... ifrequired

The development of the overall system is currently proceeding in two phases. We are about to conclude the first phase, which intends to demonstrate the proof of concept device to show that mechanical removal is feasible, repeatable, productive and safe. We have laid out the capabilities of the two different systems to be developed over the two funded phases in the table below (notice that the system is also being designed to be remotely as well as manually deployed within DOE facilities):

	PHASE I	PHASE II
Multi-diameter piping	4.5" OD; 1-2" insul.	4" to 8" OD; 1-2" insul.
Lagging	all, except SS lagging	
Operational Mode	Self-propelled	
	Cleared pipe to start	Self-starting
	Manually emplaced	Remotely emplaced
Full emission containment	removal module only	full machine if needed
L&I removal in ANY orientation	yes	
Abatement productivity	2 to 8 feet per hour	
In-situ bagging	no	yes
Waste compaction	yes (4:1 estimate)	
L&I removal around obstacles	NO (manual removal); +/-.5 ft. around hangers	
	face-cut encapsulation spray	unremoved L&I encapsulation spray
Locomotion past obstacles	no (straight runs only)	yes (remote assistance if needed)
Insulation wetting	100%	
Pipe encapsulation	100%	
Self-cleaning	no	EPA/OSHA regs
Open-face sealing around pipe and L&I	yes; high vel. to vacuum	
Automated Sensing and Control	no (Video only)	yes
User Interface	Button-box	Control Station

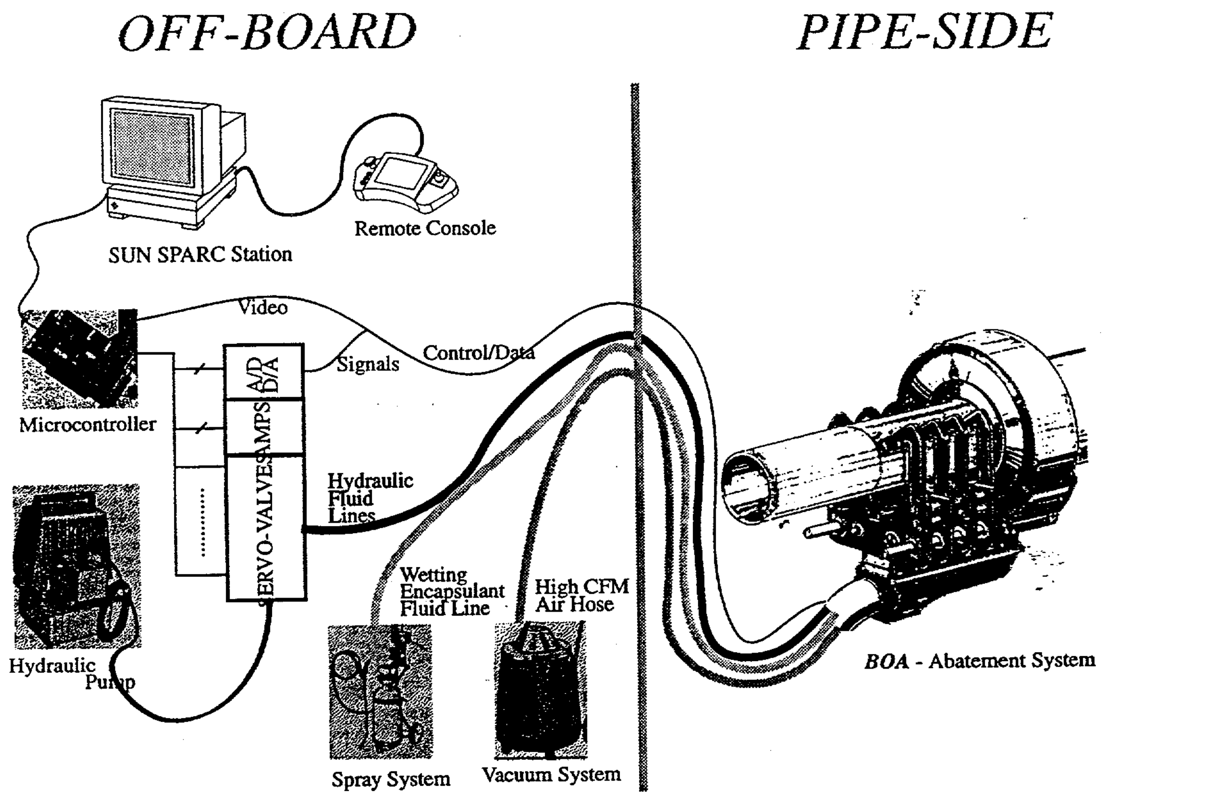

Figure 1: Overall system architecture of the *BOA* asbestos abatement system

V. SYSTEM OVERVIEW

The overall system configuration of the *BOA* asbestos abatement system is shown in Figure 1. The crawler is located on a pipe, and tethered to the off-board logistics support and control units. The crawler is hydraulically powered, with the supply and return lines connecting the actuators to the off-board hydraulic supply unit. In addition, cylinder position feedback sensors are wired to the hydraulic control racks. Other feedback and video lines are also routed in the tether assembly back to the control rack, which houses all the computing, control and power conditioning systems. The entire system is controlled from two 68HC11 (master/slave) microprocessor boards that monitor the system status and coordinate the control of all actuators through dedicated hydraulic servo controllers. The control interface consists of a portable remote console with touch-screen and joystick, with an additional SPARC II workstation for software development and graphic displays (for development and demonstration only). Video is routed to a main CRT on the control rack, as well as a small color monitor mounted atop the portable remote console.

The crawler itself, dubbed *BOA*, consists of a locomotor and remover section, where the locomotor is responsible for clamping and inching along the pipe, while the remover contains all the systems needed to remove the ACLIM from the pipe to the required cleanliness levels. A picture of the overall system and the individual locomotor and remover details is shown in Figure 2.

The individual components and their functionalities are best explained by detailing the sequence of events that are part of a complete abatement cycle. In order to better visualize the individual actions, a step-by-step sequence of figures of the inside of the remover section are shown in Figure 3 - the cross-section view is obtained by taking a forward-looking perpendicular cut to the longitudinal axis of the pipe-section the crawler sits on.

BOA clamps onto the pipe and inches along the pipe using a dual tripod clamping mechanism connected by guide-rails and a linear hydraulic actuator. The clamping force is achieved using a set of linkages powered by a single hydraulic piston. A 6-inch advance sets the crawler up for the removal process which encompasses a set of longitudinal and circumferential cuts made using two separate circular concrete/diamond-tip saw-blades powered with an electric DC motor. Lagging materials that we expect to have to cut through range from aluminum, to clamps, chicken-wire, tape, and plaster-tape. Rotating c-gears then place a set of rotating paddles into the longitudinal cut(s), allowing the gears to move in opposite

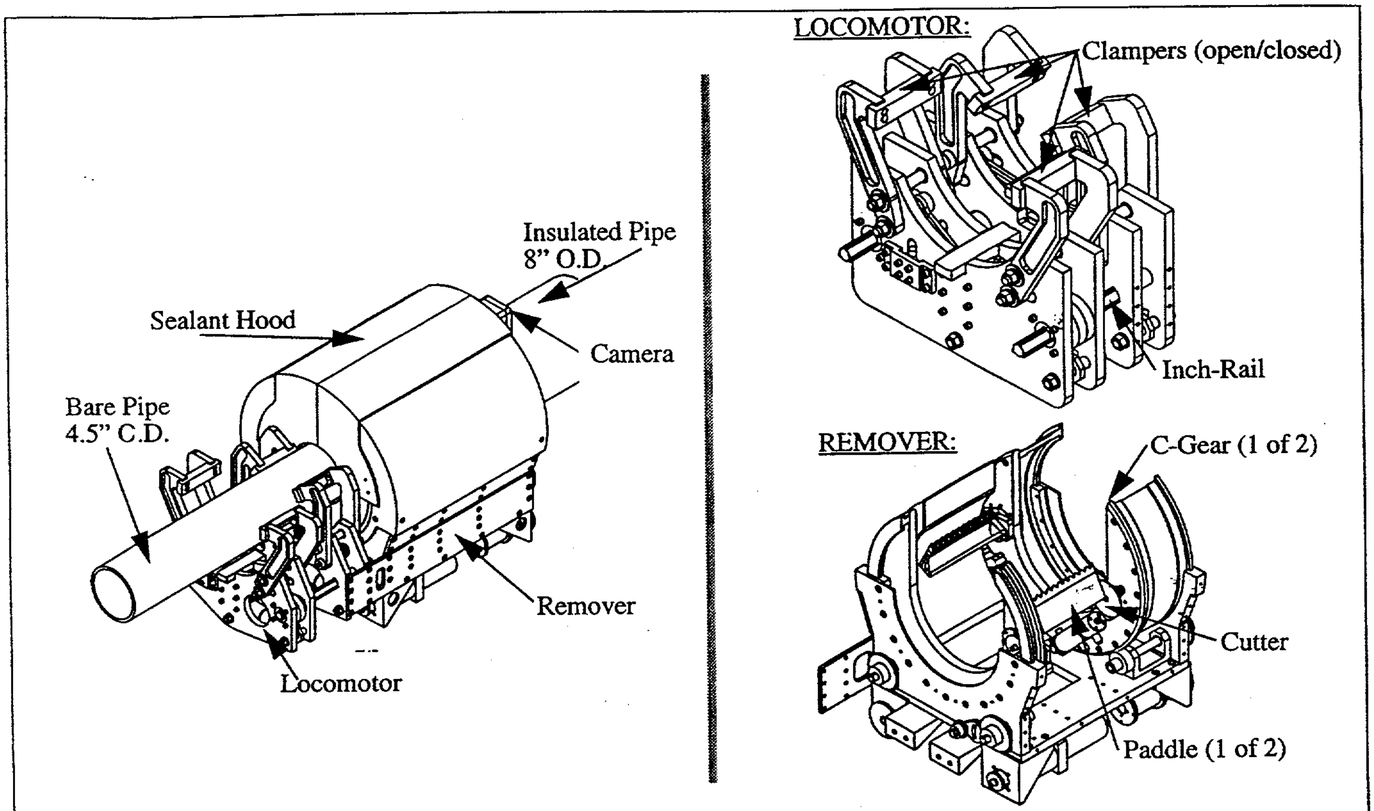

Figure 2: Detailed view of the *BOA* crawler and detailed views of the locomotor and remover sections

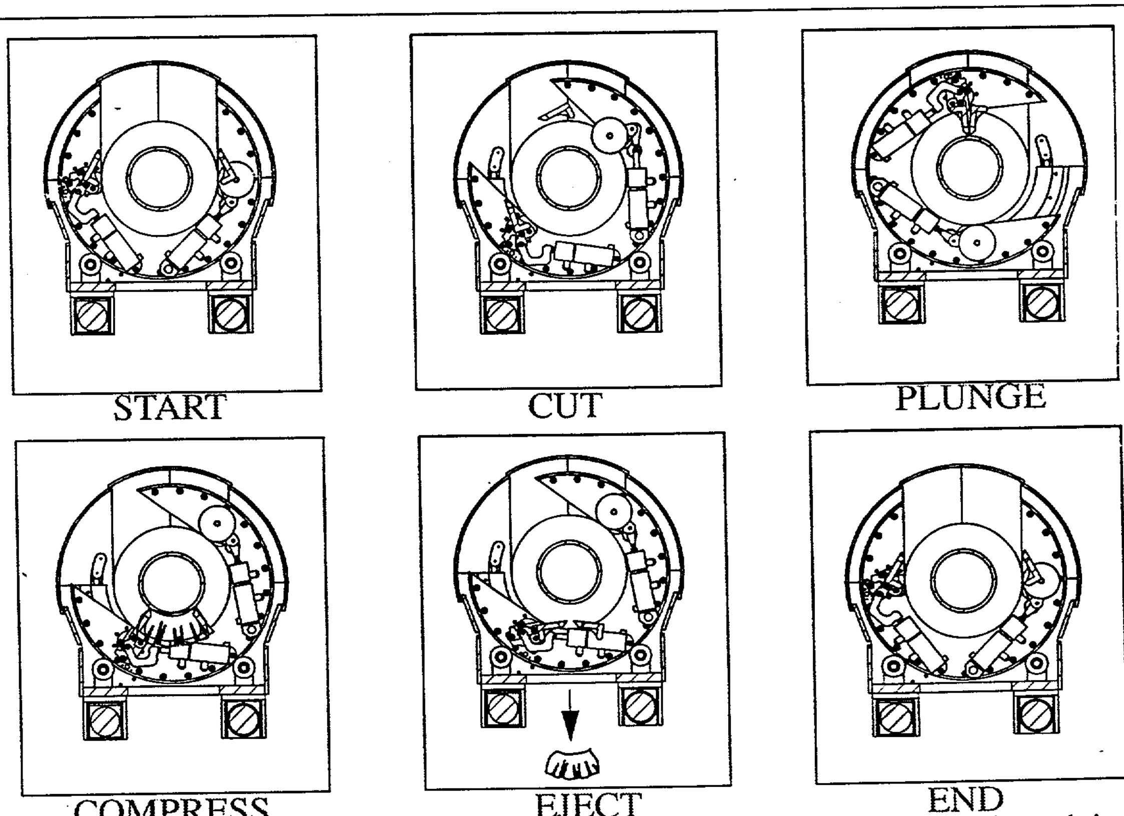

Figure 3: Cross-sectional views of a step-by-step procedure of ACLIM cutting, compression and ejection

directions to compress the ACLIM. Insulation materials we expect to find range from *Calsil* and *Magblock* (tradenames) which are like very hard foam-board, to fiberglass-like blown insulation, wrapped (and possibly tared) card-board material, and finally completely *friable*[1] insulation material. Adhesion of the insulation to pipe and lagging is expected due to decades-long processes of condensation and corrosion. With a final rotation of the paddles the compressed block is ejected away from the crawler, irrespective of whether the crawler is horizontal or vertical.

The compressed block is ejected into a bagging system underneath the crawler, where the block is bagged and the bag heat-sealed for later disposal. The bagging system will continue to feed the sealed sections of removed ACLIM, resulting in a line of 'sausage-links' which are either placed on the floor or handled and removed by an operator.

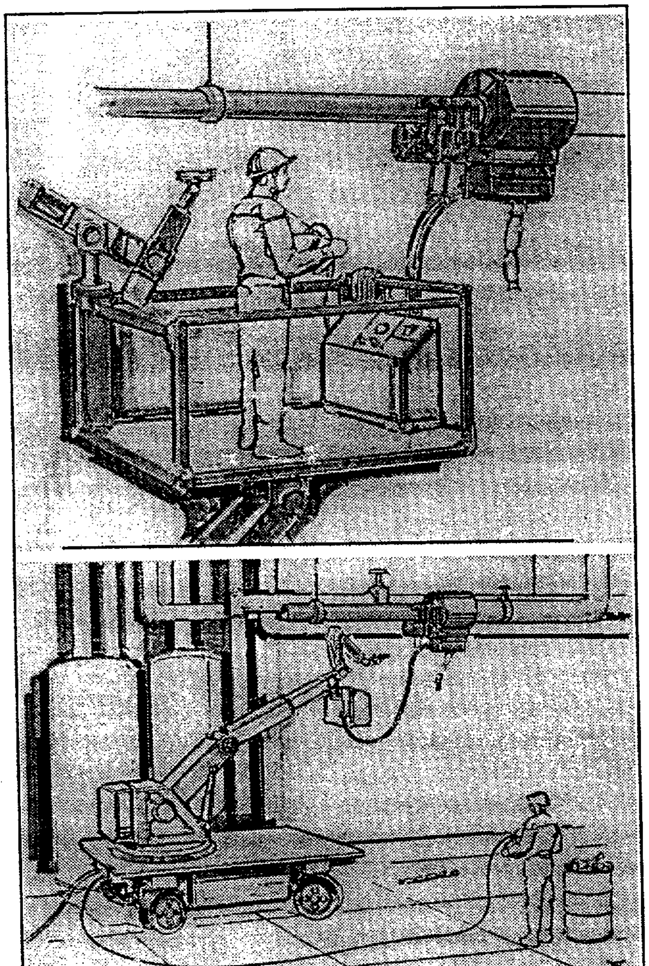

Figure 4: Robotic and manual deployment scenarios

1. defined as turning to 'powder-like' dust upon contact

A support system, whether human-assisted or robotic, emplaces the crawler onto pipe-runs between obstacles (valves, junctions, bends) and provides for long reaches, logistics support (fluids, power, materials) during the entire remediation task. Fiber-containment is achieved by sealing the entire system around the pipe, creating a high-velocity entrapment system around all seals and inside the removal module, wetting the insulation and sealing the exposed pipe, while monitoring air-quality around the system and thus obviating the need for a complete containment-area setup. An artist rendering of the final deployment scenario for a robotic and human-assisted configuration to be completed by the end of FY'95 are shown in Figure 4.

VI. ECONOMIC VIABILITY

The development of the *BOA* system is based on the knowledge that in Oak Ridge's K-25 plant, there are about 134,000 linear feet of ACLIM insulated process piping alone. Current human operator removal estimates for ACLIM abatement range from \$50 to \$100.- per linear foot. The above cost does not include the cost of disposal which is hard to get a solid number on, but \$300 per cubic foot would not be unreasonable. Manual productivity figures hover around the 1 hour per linear foot level.

Our current system attacks only straight runs of piping, leaving obstacle sections to be cleared by a human worker. which reduces the linear footage where *BOA* would be applicable by about 30%. Increased productivity should be achieved since we should be able to remove about 2 to 8 feet per hour, and also reduce the linear-footage abatement cost because of no need for a complete containment area and the potential use of several *BOA* systems working in parallel. Additionally, we compress the ACLIM *in-situ*, markedly decreasing the disposal volume and hence the associated cost. The current cost-estimate runs about \$125,000 per complete unit (75K for the crawler and 50K for the logistics unit), which yields about 5,000 feet of piping for a simplified ROI estimate.

VII. EXPERIMENTAL PLAN

We have developed a detailed experimental plan which will help us test the system at all levels. A set of functional tests will insure that all sub-systems are working properly, and that they perform their sub-tasks to specification. A set of process experiments will allow us to test the complete abatement cycle and measure actual productivity and completeness of ACLIM removal, encapsulation, fiber entrapment, etc.

At the moment of paper submission we have performed all the functional tests and are currently involved in executing the process experiments to determine overall performance parameters. Initial experiments indicate the successful operation of the abatement cycle, albeit complete cleanliness of the pipe through purely scraping action seems to be hard to insure. The degree and extent of 'baked-on' sections of insulation has a high degree of influence on how clean a pipe can be left behind. This problem will need to be addressed in the next version of the robot. A complete set of experimental results with a more graphical analysis and representation will be presented during the ANS conference.

VIII. RECOMMENDATIONS

Our recommendations are based on the assembly, debugging and experimental results obtained during the execution of this first phase of the contract. In order to organize them better, we have broken them up into individual sub-headings as follows:

- **Crawler Design**
  The crawler will have to be designed for manufacturability, and hence will require more careful attention to materials selection, tolerances, OEM components cost and availability, etc. The entire actuation system will be switched from hydraulic to electric to increase ease of maintenance and simplify operation.
- **Off-board Logistics Support Unit**
  Currently all off-board logistics support systems are separate. In the final phase they will all be integrated into a single unit, which can either be appended to a robotic endeffector or placed atop a man-lift (see Figure 4). Computing and control systems, HEPA filters and fluid systems, as well as bagging supplies will all be housed in a self-contained unit, which will be tethered to the robot system.
- **Abatement Process - Tools and Methods**
  We are currently using a rotary cutter blade, which we would like to replace with two separately actuated and-mill cutters, since chicken-wire seems to not be a frequent lagging material. We will also explore the possibility of incorporating a rotary brushing system into the remover to fully remove all baked-on particles. We are currently also evaluating the possibility of using additional cameras for the rear and inside of the crawler.
- **Operator Interface & Control Software**
  The currently used control console will be re-built and allow for the incorporation of the touch-screen and joystick into the fixed interface panel on the off-board logistics support unit. A much simpler button-box will be used as a remote pendant with which to control the most basic and high-level functions of the robot. The control software developed to date, due to its simplicity, will be re-used and expanded to allow for additional control and monitoring of the logistics support unit.

IX. DEVELOPMENT SCHEDULE

The first of two phases to be completed by November 1994, will develop a crawler robot system to work on 4-inch diameter straight-runs of pipes, capable of removing any type of lagging and insulation that is expected to be found in these facilities. The system will be demonstrated on a variety of non-ACLIMs (fiberglass) and its removal method and rate will be validated. Current estimates are that the system is quite feasible due to (i) the current high manual removal costs of contaminated ACLIM ($50.- to $100.- per linear foot), and (ii) the comparatively low productivity achievable in such an environment (less than 1 linear ft. per hour per operator). The *BOA* system is expected to at least half the cost of removal while cutting the removal time by a factor of between 2 and 4.

X. ACKNOWLEDGEMENTS

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XI. REFERENCES

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