SECTION 6 - TECHNOLOGY SAFETY DATA SHEET

TECHNOLOGY SAFETY DATA SHEET
UNIVERSITY OF SOUTH CAROLINA - CYBERMOTION, INC.
A ROBOTIC INSPECTION EXPERIMENTAL SYSTEM (ARIES)

SECTION 1: TECHNOLOGY IDENTITY	
Manufacturer's Name and Address: Cybermotion Inc. 719 Gainsboro Road, NW Roanoke, VA 24016	Emergency Contact: Ken Kennedy (540) 981-0012
	Information Contact: Ken Kennedy (540) 981-0012
	Date Prepared:
Other Names: A Robotic Inspection Experimental System	Signature of Preparer: Operating Engineers National Hazmat Program 1293 Airport Road Beaver, WV 25813 phone (304) 253-8674 fax (304) 253-7758 Under cooperative agreement DE-FC21-95 MC 32260

SECTION 2: PROCESS DESCRIPTION

The mobile robot inspection system, ARIES, has been developed for the DOE to remove workers from the potentially hazardous environment encountered during the routine inspection of drums used to store radioactive waste. The robot will roam the three-foot wide aisles of 55-gallon drums, stacked three high, making decisions about the surface condition of the drums and maintaining a database of information about each drum. The robot system will locate and identify each drum, characterize relevant surface features (such as paint blisters, dents, rusted areas, etc.), and update a database containing inspection information. A camera positioning system (CPS) positions the vision camera and any other required instrumentation packages (bar-code reader, etc.) to perform the inspection process for each drum. It is anticipated that this mobile robot system, based on a commercial mobile platform, will improve the quality of inspection, generate required reports, and relieve workers from potential low-level radioactive exposure and contamination hazards. Workers will be required for computer operations, maintenance of the system and its components, and decontamination, when necessary.

The robot consists of a 6-wheeled K3A mobile platform, a compact subturret, a sonar (sound navigation and ranging) imaging system, a laser-based lidar (light detection and ranging) navigation beacon system, and a camera positioning system. It has a sonar imaging system used in navigation and collision avoidance and an automatic docking/charging system. Drum-referencing algorithms and camera-positioning algorithms have been included in the primitive instruction set for the robot. The vehicle for the mobile autonomous robot is commercially available, and is capable of unsupervised navigation in a variety of semi-structured environments. The robot's navigation is based on "SynchroDrive," a patented design that utilizes concentric shafts to distribute drive and steering power to the six wheels simultaneously. This gives the vehicle an ability to dead-reckon its navigation with good accuracy to any given locale over rough and dynamic indoor terrain. The K3A platform is equipped with several onboard and offboard computers. The navigation computer is located in the vehicle base and manages the drive and steering functions. The collision avoidance computer resides in the movable turret and oversees the data acquisition from eight ultrasonic transducers (also located in the turret). ARIES uses a *virtual path* concept in which only a limited amount of information needs to be provided to the control computer in order to get the vehicle moving. Low-level, real-time control algorithms perform dead-reckoning navigation with relatively low-cost sensor and computing hardware. The vehicle updates its estimated position in a Cartesian coordinate plane with every 0.07 inches that it travels regardless of how locomotion is obtained. While navigating a path, the PID drive and steering controllers are initiated every 0.1 seconds to correct any perceived errors accumulated as the vehicle travels.

Referencing instructions provide dynamic navigational corrections to the vehicle by referencing the system to walls, halls, doorways, etc.

SECTION 2: PROCESS DESCRIPTION

The additional special computer systems for ARIES consist of an onboard management system and an offboard supervisory system. The onboard system, housed in the subturret, provides control of the inspection processes and manages other onboard activities. Low-level primitive instructions used by the drum navigation algorithms have been added to the instruction set of the K3A. The onboard computers are essentially transparent to the operator during autonomous operations. Standard UNIX workstations are used for the offboard supervisory computers. The software is written to be portable across most UNIX systems and currently runs on Silicon Graphics, DEC, HP, and Sun workstations. Silicon Graphics systems are used for development purposes and some 3-D features require this system for acceptable performance. Provisions have been made for alternative representations in other systems. The offboard system provides three primary functions: (i) functional compatibility with the PC-based software provided by Cybermotion for control and programming of the basic robot; (ii) programming tools for creating the mission program; and (iii) the ability to monitor and control the robot during the inspection process. An assembler for the virtual path language of the robot has been provided. The assembler operates in the DOS and UNIX environment. The offboard computers are used by operators for mission setup, monitoring and control when human interaction is necessary.

Offboard computers networked via wireless Ethernet with onboard computers provide the high-level planning, monitoring, reporting, and general supervision of ARIES. Multiple control and monitoring stations may be employed. Planning and inspection task (the *mission*) begins with the implementation of a world representation of the robot's environment (the Robot World). A path planner automatically generates robot path programs for user-specified paths, based on the site description contained in the robot world. The mission program, used to control the inspection process, is downloaded from the offboard system to the onboard computer where it is executed. The offboard systems may be used to monitor and control the system during the inspection process.

The *mission* represents the system description of the tasks to be performed by the robot. The mission is created by the Site Manager (mission *planning)*, down-loaded to the robot, (mission *assignment*), and executed by the onboard Mission Controller.

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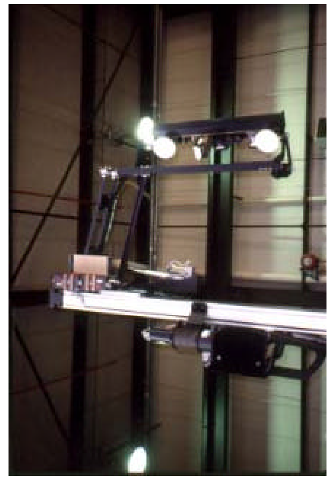
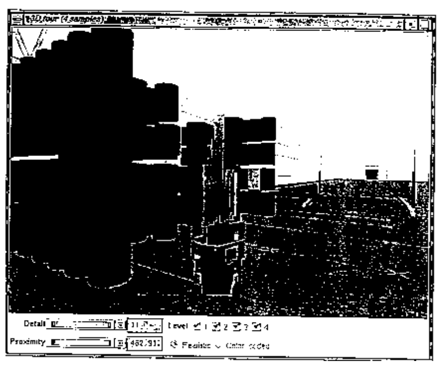
The Site Manager may be used off-line to plan and create a mission or on-line to control and/or monitor the operation of the robot. It is the user's primary access to the system at the task level. The Mission Controller is charged with the task of carrying out the mission. It is a peer of the Site Manager in that it receives the mission from the Site Manager. However, it is primarily a real-time program, since it directly controls the robot during the survey. The mission consists of (I) the mission script, a high-level description of the mission used by the onboard Mission Controller, (ii) the Path library, a set of path programs that may be used to travel between the nodes included in the survey area, and (iii) a local copy of the drum list.

The mobile platform transports an inspection application payload that includes a mechanical fixed-mast deployment system, the CPS. The inspection payload consists of color and black and white cameras, bar-code scanner, and strobe lighting. For the drum inspection process, at each stack of drums (three drums in height), the CPS deploys the inspection module at various heights on the drums required by the vision system. A major component of the inspection module is the vision system. It is used to analyze the drums' external and visible conditions and to determine their structural integrity. The overall function of the vision module is to locate *suspect* drums and to report their condition. Once drums have been located by the robot's navigation system, visual assessment of drum condition is primarily an autonomous assessment of visible and quantifiable surface characteristics.

SECTION 3: PROCESS DIAGRAMS





SECTION 4: CONTAMINANTS AND MEDIA
The contaminant of greatest concern with ARIES is the lead-acid batteries used to power the base of the robot. The batteries used to power the base of the robot are 12 volt 85 amp. sealed lead-acid. Under normal circumstances there should not be any exposure to the hazardous constituents of the battery but the potential for exposure to lead and lead contaminated sulfuric acid must be realized and proper precautions must be used. This may include handling the batteries utilizing personal protective equipment (PPE), when appropriate, training personnel in the hazards associated with lead-acid batteries, and proper storage and waste disposal. In 1985, the Environmental Protection Agency (EPA) declared lead-acid batteries to be hazardous waste.

SECTION 5: ASSOCIATED SAFETY HAZARDS	
Probability of Occurrence of Hazard: 1 Hazard may be present but not expected over background level 2 Some level of hazard above background level known to be present 3 High hazard potential 4 Potential for imminent danger to life and health	
A. ELECTRICAL (LOCKOUT/TAGOUT)	RISK RATING: 3
There are electrical hazards associated with the charging station, the lead-acid batteries, and the computer components in the base of the robot. The probe on the charging station carries a low voltage and could cause a mild shock if touched while the robot is docking. When changing the lead-acid batteries in the base of the robot, there is the potential for sparking from the battery wire accidentally coming into contact with the frame of the base. This could result in a shock and/or burn hazard to the worker. There is no electrical disconnect. Reaching into the energized computer components may cause an electrical shock. Standard Operating Procedures (SOP's) to include lockout/tagout procedures to be used, when maintenance must be performed, need to be developed.	
B. FIRE AND EXPLOSION	RISK RATING: 2
There is the possibility of the production of hydrogen gas during the charging of the lead-acid batteries. Due to the flammable and explosive properties of hydrogen, this needs to be taken into consideration when the location of the charging station is chosen. There should be no open flames or external ignition sources in the area of the charging station.	

C. CONFINED SPACE ENTRY	RISK RATING: N/A
Not part of this technology.	
D. MECHANICAL HAZARDS	RISK RATING: 2
There are pinch points associated with several belts located on the lower part of the mast assembly. These should be guarded and labeled as pinch points.	
E. PRESSURE HAZARDS	RISK RATING: N/A
Not part of this technology.	
F. TRIPPING AND FALLING	RISK RATING: 2
The fiduciaries used for robot navigation are tripping hazards. Workers should be made aware of their location and the area around them marked off.	
G. LADDERS AND PLATFORMS	RISK RATING: N/A
Not part of this technology.	
H. MOVING VEHICLES	RISK RATING: 3
A forklift is required to lift the mast onto the base of the robot. Proper forklift safety should be observed. It needs to be assured that all warning devices on the forklift such as the backup alarm are in operating condition at all times and the forklift operators are properly trained. The robot itself may be considered a moving vehicle. There is the potential the robot may not see a worker or part of a worker (such as a foot) and run into him/her or over a part of him/her. Workers need to be aware of the robots location and programmed path anytime they are working in the same area as the robot. The current limit drive servo needs to be set at the lowest possible power which will still allow the robot to perform its mission but lower the risk of running into/over any workers in the area.	
I. BURIED UTILITIES, DRUMS, AND TANKS	RISK RATING: N/A
Not part of this technology.	
J. PROTRUDING OBJECTS	RISK RATING: 2
The probe on the charging station sticks out and could easily be run into. This may injure the person and/or break the probe. It is recommended that the probe be brightly colored or a brightly colored marker be placed on it so it is more easily seen. Additionally, the charging station should be placed well out of the flow of traffic areas. The charging station area could also be marked off so workers could not get close enough to it to come into contact with the probe.	

K. GAS CYLINDERS	RISK RATING: N/A
Not part of this technology.	
L. TRENCHING AND EXCAVATIONS	RISK RATING: N/A
Not part of this technology.	
M. OVERHEAD LIFTS	RISK RATING: N/A
Not part of this technology.	
N. OVERHEAD HAZARDS	RISK RATING: 2
There is the potential for an overhead hazard to be created by ARIES knocking into a drum that is located above floor height. Overhead hazards such as pipe racks that the mast of ARIES could run into need to be taken into consideration when the mission is programmed.	

SECTION 6: ASSOCIATED HEALTH HAZARDS	
A. INHALATION HAZARD	RISK RATING: 1
Inhalation hazards associated with ARIES would be in connection with the type of environment in which it is scheduled to be operated. This should be assessed by the site characterization and an appropriate air sampling plan developed. There is the potential for some inhalation hazards if the lead-acid batteries were to leak.	
B. SKIN ABSORPTION	RISK RATING: 1
Skin absorption would be a concern if the lead-acid batteries were to leak. Appropriate PPE needs to be utilized before handling a leaking battery or cleaning up a spill from a leaking battery.	
C. HEAT STRESS	RISK RATING: 1
If a worker must retrieve ARIES by entering a contaminated area dressed in the appropriate PPE, heat stress may become a concern, especially if impermeable chemical protective clothing is required. This hazard will need to be considered on a site-by-site job-by-job basis.	
D. NOISE	RISK RATING: N/A
ARIES does not generate any noise of significant level.	
E. NON-IONIZING RADIATION	RISK RATING: 2
The lasers mounted on the mast of ARIES and used in the laser-based light detection and ranging (lidar) navigation beacon are Class IIIb lasers. Direct viewing as well as diffuse reflections of the beam of a Class IIIb laser is hazardous to the eye, in particular the retina. The laser should *never* be viewed directly or with any type of telescopic device. Persons working in an area where the potential exists to be in the direct or reflected view of the laser beam need to use goggles developed specifically for laser use. All persons working with or performing any type of maintenance activities on the laser must be trained in laser safety.	

SECTION 6: ASSOCIATED HEALTH HAZARDS	
F. IONIZING RADIATION	RISK RATING: N/A
Not part of this technology.	
G. COLD STRESS	RISK RATING: 1
Cold stress will be determined by the environment in which ARIES is operating. The extent of this hazard needs to be determined on a site-by-site job-by-job basis.	
H. ERGONOMIC HAZARDS	RISK RATING: 4
The robot, including the base with subturret and mast, and the associated system components must be loaded and unloaded from the transport vehicle. The base of the robot with the subturret can be manually "walked" off or on to the vehicle but the mast and all other components must be hand-carried. The main concern is the mast. The mast which weighs approximately 300 pounds is contained in a wooden crate-like structure used to carry it. Although there are handles located on the crate for carrying, there is a great potential for severe back injury and/or injury to the shoulders/arms/hands from workers having to lift and carry this amount of weight. There is also potential for ergonomic stressors to the back and shoulders/arms/hands from lifting and carrying other system components. Uncrating/crating the mast may require bending, lifting, stooping, and/or kneeling. These activities increase the ergonomic stressors placed on the back, legs, knees, shoulders, and arms. Additionally, uncrating/crating requires the crate to be disassembled from around or assembled around the mast. This requires removing/placing of screws and nails, which at times are in difficult to reach locations.	
I. OTHER	RISK RATING: 2
Laser (see E under this section)	

SECTION 7: PHASE ANALYSIS
A. CONSTRUCTION/START-UP
The robot, including the base with subturret and mast, and the associated system components must be loaded and unloaded from the transport vehicle. The base of the robot with the subturret can be manually “walked” off of or on to the vehicle but the mast and all other components must be hand-carried. The main concern is the mast. The mast which weights approximately 300 pounds is contained in a wooden crate-like structure used to carry it. Although there are handles located on the crate for carrying, there is a great potential for severe back injury and/or injury to the shoulders/arms/hands from workers having to lift and carry this amount of weight. There is also potential for ergonomic stressors to the back and shoulders/arms/hands from lifting and carrying other system components. Uncrating/crating the mast may require bending, lifting, stooping, and/or kneeling. These activities increase the ergonomic stressors placed on the back, legs, knees, shoulders, and arms. Additionally, uncrating/crating requires the crate to be

SECTION 7: PHASE ANALYSIS

disassembled from around or assembled around the mast. This requires removing/placing of screws and nails, which at times are in difficult to reach locations. A forklift must be used to lift the mast onto the base of the robot. Specially designed extensions for the forks are used during this maneuver. The mast is not stable during this move and must be steaded and guided by hand. This presents the potential for a hand or arm to be placed between the mast and the base. Proper precautions and proper forklift safety must be used.

B. OPERATION

The fiduciaries used for robot navigation are tripping hazards. In addition, they are easily moved, by tripping on them, which could cause navigational problems for the robot. Marking the base of the fiduciary with a brighter color (they are black) or marking off the area around the fiducial would make them more noticeable. In addition, weighting the base of the fiducial so it will not move so easily when it is bumped would help with the navigational problems that could be created.

There are electrical hazards associated with the charging station, the lead-acid batteries, and the computer components in the base of the robot. The probe on the charging station carries a low voltage and could cause a mild shock if touched while the robot is docking.

When changing the lead-acid batteries in the base of the robot, there is the potential for sparking from the battery wire accidentally coming into contact with the frame of the base. This could result in a shock and/or burn hazard to the worker. An electrical disconnect is not provided. Reaching into the energized computer components may cause an electrical shock. The computer drawer cover needs to be labeled as an electrical hazard.

The laser used on ARIES in the laser-based lidar navigation beacon system is a Class IIIb. Direct viewing as well as diffuse reflections of the beam of a Class IIIb laser is hazardous to the eye, in particular the retina. Anyone working in the area where there is the potential to in direct view or reflected view of the laser beam needs to use goggles developed specifically for laser use. In addition, all persons working with or performing any type of maintenance activities on the laser must be trained in laser safety.

During robot operation, tipping is a concern. There are two areas of concern associated with tipping, the first being that when the robot does not see an obstacle and runs into it, the robot may attempt to go over the obstacle which could cause the robot to tip. The robot tipping could result in severe injury if it were to fall on or strike a worker. Additional problems could be caused if the robot tipped and knocked over a drum and caused a spill. This has the potential to expose workers to a variety of contaminants. In addition, workers would have to enter the area to clean up the spill.

SECTION 7: PHASE ANALYSIS
The robot may also become contaminated which presents additional problems which will be discussed in a later section of this report. The second situation which causes concern for creating a tipping hazard, is an obstacle sticking out at a height above the ground whereby it hits the mast of the robot. The sonar would not "see" the obstacle at that height and the robot would continue until it ran into the obstacle. If the robot continues forward and the obstacle did not move the robot may tip until it falls over.
C. MAINTENANCE
When changing the lead-acid batteries in the base of the robot, there is the potential for sparking from the battery wire accidentally coming into contact with the frame of the base. This could result in a shock and/or burn hazard to the worker. Reaching into the energized computer components may cause an electrical shock. Standard Operating Procedures (SOP's) to include lockout/tagout procedures to be used when maintenance must be performed need to be developed. The Class IIIb laser presents a potentially severe eye hazard and burn hazard. Anyone working with or performing maintenance on the laser must be trained in laser safety.
D. DECOMMISSIONING
Due to the design of the mast and its camera payload arm, it appears to be virtually impossible to decontaminate this section of the robot. Water cannot be used to decontaminate this part of the robot due to all of the open electrical connections and wiring. Where the wiring, chains, and belts run through conduit, the conduit is an open design which also makes decontamination difficult. Special care needs to be taken when assessing ARIES to determine if it is “clean”.

SECTION 8: HEALTH AND SAFETY PLAN REQUIRED ELEMENTS
A. AIR MONITORING
Air monitoring needs to be conducted for the environment in which ARIES is operating. The specific contaminants that monitoring needs to be conducted for will be determined by the site characterization. There is not any specific air monitoring that needs to be done in association with ARIES operation.
B. WORKER TRAINING
Workers must be trained in the specific operation of the system. This will include the operation of the computer system. Additional training required may include but not be limited to Hazardous Waster Operations and Emergency Response (HAZWOPER), Hazard Communication (HAZCOM), PPE, lockout/tagout, radiation worker II, ergonomics, electrical safety, laser safety, forklift training, hand signal communication, and construction safety and/or general industry safety.

SECTION 8: HEALTH AND SAFETY PLAN REQUIRED ELEMENTS

C. EMERGENCY RESPONSE

Emergency response and preparedness must be part of every hazardous waste site health and safety plan (HASP). During normal operation of ARIES there is not any indication for any out of the ordinary emergencies. However, emergency situations could arise if there were problems such as ARIES tipping or running into something that could potentially knock over and spill a waste drum. This would then require emergency response activities to be put into motion.

All workers must be trained to operate the emergency shut off controls located on ARIES and the manual pendant control. Additionally, they need to trained to handle any emergencies that may occur in the area where ARIES is operating.

The operator located at the operation station may be out of "line of sight" with ARIES and not be able to see where the robot is or what it is doing in real-time. An emergency situation may occur and not be realized until someone enters the area. This could be remedied by installing a real-time video camera on ARIES that would provide visual feedback to the operator as to ARIES' location and the present operational conditions at any point in time.

Electrical hazards and the potential for leaking lead-acid batteries are the two main concerns for responders to an emergency involving ARIES. A complete shutdown of the system and the use of the proper PPE may be necessary before responding to such an emergency.

D. MEDICAL SURVEILLANCE

An eye examination with particular attention to the retina should be conducted for anyone working in the area with the Class IIIb laser.

E. INFORMATIONAL PROGRAM

Under Occupational Safety and Health Administration's (OSHA's) Hazardous Waste standard, 29 CFR 1910.120, the employer is responsible for providing information on new technologies to the workers who will be using the equipment.

SECTION 9: COMMENTS AND SPECIAL CONSIDERATIONS

From the perspective of software usage, consideration should given to three types of users for the system: (1) the expert, who is the person that knows the details of the operation of the robot, its programming and the internal hardware. This may be a representative of the developer; (2) the programmer, who is the person that programs the aisle paths, location of the fiduciaries, etc. This person must have the knowledge (training) required to use the "Site Manager" and other software provided by the developer to program the path and normal operational features of the robot. This person may have limited knowledge of the internal workings of the robot and internal programming details such as UNIX codes; and (3) the operator, who will start the

SECTION 9: COMMENTS AND SPECIAL CONSIDERATIONS
robot operation for each mission, after which the robot will perform its tasks. If the robot stalls, the operator would take it out to a safe location and report the incident to the supervisor. The operator would not be required to have any knowledge of the software/hardware aspects of the robot.