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ANL/D&D/TM-95/1

A Survey of Commercially Available Manipulators, End-Effectors, and Delivery Systems for Reactor Decommissioning Activities

Decontamination and Decommissioning Program

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Operated by The University of Chicago,
under Contract W-31-109-ENG-38, for the
United States Department of Energy

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Director, Technology Development Division
Argonne National Laboratory
Argonne, Illinois 60439-4815
Telephone (708) 252-6050

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by Donald R. Henley and Thomas J. Litka*

Decontamination and Decommissioning Program, Technology Development Division,
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

May 1996

Work sponsored by United States Department of Energy,
Office of Environmental Management

**Litka is affiliated with Advanced Consulting Group, Incorporated, Chicago, Illinois.*

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A SURVEY OF COMMERCIALY AVAILABLE MANIPULATORS, END-EFFECTORS, AND DELIVERY SYSTEMS FOR REACTOR DECOMMISSIONING ACTIVITIES

by

D.R. Henley and T.J. Litka

SUMMARY

Numerous nuclear facilities owned by the U.S. Department of Energy (DOE) are under consideration for decommissioning. Currently, there are no standardized, remote, automated systems designed to dismantle and thereby reduce the size of activated reactor components and vessels so that they can be packaged and shipped to disposal sites. Existing dismantling systems consist of customized tooling that has been developed to dismantle a specific reactor system. A standardized, remote, automated system is therefore needed to deliver the specific tooling required for dismantling reactor systems at different locations.

A standardized dismantling system is expected to be the most cost-effective means of dismantling and removing reactors. The system requires one or more manipulators (i.e., robotic arms), multiple end-effectors, and a delivery system. The manipulators with end-effectors can perform various tasks, such as cutting and removing reactor components. Numerous manipulators are available. Some standard end-effectors are available, but many are unique. The delivery system for the manipulator most likely would be a gantry or overhead crane, but other types of booms and lifts should be considered. Delivery systems (such as cranes and gantries) are usually custom designed and built for a specific application.

A standardized dismantling system would provide the DOE community, commercial utilities, and the public with many benefits. For example, the system could be designed for the decommissioning and decontamination of fuel storage pools, hot cells, and fuel-reprocessing canyons. To save money and improve reliability, the new system should be based on currently available hardware, which can be procured from private industry. The tasks of fabricating and supplying dismantling systems will ultimately be transferred to the private sector.

The purpose of this document is to survey the commercially available equipment that could be assembled to produce such a universal dismantling system. To provide this information, Argonne National Laboratory contacted more than 70 suppliers of manipulators and cranes/gantries. Argonne

categorized the suppliers and presents them in this report. In addition, Argonne provides some detailed information about each manipulator, as well as a list of standard end-effectors.

1 INTRODUCTION

1.1 PURPOSE

Numerous nuclear facilities owned by the U.S. Department of Energy (DOE) are under consideration for decommissioning. Currently, there are no standardized, automated, remote systems designed to dismantle and thereby reduce the size of activated reactor components and vessels so that they can be packaged and shipped to disposal sites. Existing dismantling systems usually consist of customized, facility-specific tooling that has been developed to dismantle a specific reactor system. Such systems have a number of drawbacks. Generally, current systems cannot be disassembled, moved, and reused. Developing and deploying the tooling for current systems is expensive and time-consuming. In addition, the amount of manual work is significant because long-handled tools must be used; as a result, personnel are exposed to excessive radiation.

A standardized, automated, remote system is therefore needed to deliver the tooling necessary to dismantle nuclear facilities at different locations. Because this system would be reusable, it would produce less waste. The system would also save money because of its universal design, and it would be more reliable than current systems.

An industry objective is to develop a universal system for dismantling reactors and removing reactor components. Such a system would be the most cost-effective approach to decommissioning nuclear facilities. To be effective, each component of the dismantling system should be commercially available (or as close to being commercially available as possible) and exemplify the latest technology. The dismantling system would probably consist of a manipulator, multiple end-effectors, and a delivery system (see Figure 1). The manipulator and end-effectors would perform various tasks, such as cutting and removing reactor components. The delivery system would most likely consist of a mast, an overhead crane, or a gantry, but other types of booms and lifts or motorized vehicles might also be appropriate. Each of these delivery systems has unique advantages and disadvantages.

Such a standardized dismantling system could provide the DOE community, commercial utilities, and the public with many benefits. For example, the system could be designed for the decommissioning and decontamination of fuel storage pools, hot cells, and fuel-reprocessing canyons. To save money and improve reliability, a new dismantling system should be based on commercially available hardware. The tasks of fabricating, supplying, and deploying dismantling systems will ultimately be transferred to the private sector.

FIGURE 1 Typical Arrangement of a Manipulator, End-Effector, and Bridge Crane

1.2 INFORMATION GATHERING

Argonne National Laboratory (ANL), through funding by the Office of Technology Development (EM-50), has surveyed the manufacturers of commercial equipment that might be used to perform remote decommissioning and decontamination tasks at DOE facilities. More than 70 suppliers were contacted for information. Every effort was made to make this survey as comprehensive as possible. To help achieve that goal, the suppliers were all asked to review the information presented in the tables in this report.

To gather information for this report, Argonne:

- Gathered and reported information on all applicable equipment,
- Used commercial nuclear industry purchasing reference publications to identify suppliers (see publications 1 through 4 in the Bibliography),

- Investigated non-nuclear suppliers on the basis of referrals from the nuclear suppliers, and
- Contacted U.S. suppliers and foreign suppliers with U.S.-based offices.

An additional source of information on robotics is the Internet. Some particularly useful resources are listed below.

- Robotics Internet Resources Page:
<http://piglet.cs.umass.edu:4321/robotics.html>.
- NASA's Jet Propulsion Laboratory Robotics Homepage:
<http://robotics.jpl.nasa.gov>.
- Robotics Frequently Asked Questions List:
<http://www.frc.cmu.edu:80/robotics-faq>.

This last homepage provides a link to a very extensive list of companies that manufacture and sell robotic equipment.

1.3 PRESENTATION OF INFORMATION

All of the data obtained are presented in Section 2 of this report. The report consists of sections that describe manipulators, end-effectors, and delivery systems. Information about suppliers of manipulators and delivery systems is divided into subsections. Controls are discussed in the section on manipulators. Information is summarized in tables whenever possible so that equipment can be compared easily. Cost estimates are given only if they were provided by the suppliers and are included for information only.

2 COMMERCIAL AVAILABILITY OF EQUIPMENT

2.1 MANIPULATOR INFORMATION

2.1.1 Suppliers Contacted and Categories

Numerous types of manipulators are available for reactor decommissioning. Nuclear industry purchasing publications list many suppliers as being involved with remote handling/robotics. Some of these suppliers have commercially available manipulators for procurement, but many do not. Robotic industrial welding arms are also available, but they are not described in this report.

Argonne contacted the 54 suppliers listed in Appendix A to determine if they had commercially available manipulators. After reviewing the information provided by the suppliers, Argonne developed a categorization that describes the industry. The categories and numbers of suppliers of manipulators are listed in Table 1. Note that several suppliers provide equipment in more than one category.

TABLE 1 Categories and Numbers of Suppliers of Manipulators

Category	Description	Number of Suppliers
RA1	Commercially available manipulators with controls	8
RA2	Provide manipulators that have been used several times but have not been offered as commercial (near-commercial status)	2
RA3	Develop unique manipulators for an application	4
RA4	Purchase manipulators and package them for an application	10
RA5	Provide crawlers and/or remotely operated vehicles (ROVs)	14
RA6	Develop and provide controls for manipulators only	2
RA7	Do not offer any robotic equipment or services	19

The suppliers of manipulators in categories RA1 through RA6 are listed below (for more information on each supplier, see Section 4):

RA1 Commercially Available Manipulators with Controls

AEA Technology, Pittsburgh, PA (United Kingdom)
 BNFL, Inc., Walnut Creek, CA (United Kingdom)
 Brokk, Seattle, WA (Sweden)
 GEC Alsthom Schilling Robotic Systems, Inc., Davis, CA (United Kingdom)
 Kraft TeleRobotics, Inc., Overland Park, KS
 PaR Systems, Inc., Shoreview, MN
 Sarcos, Inc., Salt Lake City, UT
 Western Space and Marine, Santa Barbara, CA

**RA2 Provided a Manipulator Several Times
 ("near commercial")**

Omniview, Inc., Knoxville, TN
 Spar Aerospace Limited, Avon, CT (Canada)

RA3 Develop Unique Manipulators for Specific Applications

AECL Technologies, Rockville, MD (Canada)
 ASI Robotics Systems, Clawgon, MI
 Nuclear Systems Associates, Brea, CA
 Odetics, Anaheim, CA

**RA4 Purchase Manipulators and Package Them for Specific
 Applications**

The Bartholomew Co., Inc., Westbury, NY
 General Atomics, San Diego, CA
 NAC International, Norcross, GA
 NES, Inc., Danbury, CT
 NUS, Clearwater, FL
 Oceaneering Technologies, Rockville, MD
 PLS International, Cleveland, OH

RedZone Robotics, Inc., Inc., Pittsburgh, PA
 Resource Services International, Cleveland, OH
 Rust Utility Services, Inc., Essex, CT

RA5 Provide Crawlers or ROVs

AECL Technologies, Rockville, MD (Canada)
 ARD Corp., Columbia, MD
 Benthos, Inc., N. Falmouth, MA
 Brokk, Seattle, WA (Sweden)
 Cybermotion, Inc., Salem, VA
 Foster-Miller, Inc., Waltham, MA
 Grove Worldwide, Shady Grove, PA
 Kraft TeleRobotics, Inc., Overland Park, KS
 Remotec, Oak Ridge, TN
 ROV Technologies, Inc., Vernon, CT
 Spar Aerospace Limited, Avon, CT (Canada)
 Viking Systems International, Pittsburgh, PA
 Visual Inspection Technologies, Flanders, NJ
 Western Space and Marine, Santa Barbara, CA

RA6 Provide Controls for Manipulators Only

Deneb Robotics, Inc., Auburn Hills, MI
 Silma, Inc., Cupertino, CA

In addition to companies that produce conventional manipulators, Central Research Laboratories (Redwing, MN) and R.W. Wiesener, Inc. (Albermarle, NC) provide hot-cell, through-wall manipulators. These types of manipulators have not been addressed in this study.

Most suppliers of manipulators in Categories RA1 through RA4 are also system integrators that use commercial manipulators, gantries, cranes, or other positioners all operated from a single controller. These suppliers purchase equipment if available, design it if it is not available, and supply the controls needed for the application. They may also develop special end-effectors.

2.1.2 Specifications and Cost Estimates

Detailed information can be provided only for manipulators in categories RA1 and RA2.

2.1.2.1 Hydraulically Powered Manipulators

The suppliers of Categories RA1 and RA2 equipment have provided specifications and cost estimates for hydraulically powered manipulators. This information is given in Tables 2 and 3.

2.1.2.2 Electrically Powered Manipulators

The suppliers of Categories RA1 and RA2 equipment have provided the specifications and cost estimates for electrically powered manipulators. This information is given in Tables 4 and 5.

2.1.3 Controllers

A controller is required to control the motions and path of each robotic element. The simplest controller is a manually operated hydraulic or electrical joystick. More sophisticated controllers are usually computer-based and have such features as programmed cutting paths, teach-and-learn capabilities, force feedback, and collision avoidance. Computer-based controllers can usually control more than one manipulator, and they can coordinate the motion of a manipulator, a crane, a gantry, or a mast. Because the various controllers vary in sophistication, their prices often vary by more than a factor of 10. Table 6 lists the features of the controllers supplied by several suppliers.

2.2 END-EFFECTOR INFORMATION

2.2.1 Standard End-Effectors

A number of standard end-effectors are commercially available. Argonne asked robotic-equipment suppliers to provide information about their end-effectors. Some suppliers have what they consider to be "standard" end-effectors. All equipment suppliers indicated that end-effectors are often unique and are developed and packaged for specific applications. Survey information will be presented only for end-effectors considered to be standard products. Only 6 of the 13 Category RA1, RA2, and RA3 suppliers of manipulators have standard end-effectors. Even these standard

TABLE 2 Category RA1 — Specifications of Hydraulically Powered Manipulators (Commercially Available)

Specification	Supplier and Name of Manipulator				
	Brokk: BM3000 (see Figure 2)	GEC Alsthom Schilling: Conan T (see Figure 3)	GEC Alsthom Schilling: Hydra T (was Gamma HV6F) (see Figure 4)	GEC Alsthom Schilling: RigMaster (see Figure 5)	GEC Alsthom Schilling: Titan III T (was Titan II) (see Figure 6)
Weight (lb)	4,070	240	45	135	223
Maximum reach (in.)	171	66.5	36	51.8	75.4
Degrees of freedom	5 plus grip	6 plus grip	5 plus grip	4 plus grip	6 plus grip
Maximum payload at full extension (lb)	1,700	375	80	400	250
Boom	NA	NA	NA	105° range	270° range
Shoulder azimuth yaw	360° range	120° range	NA	105° range	120° range
Shoulder pitch (pivot)	68° range	120° range	120° range	NA	NA
Shoulder roll (rotate)	NA	NA	90° range	12 in.	NA
Elbow pitch (pivot)	80.5° range	120° range	120° range	NA	270° range
Wrist yaw (side pivot)	NA	120° range	120° range	NA	180° range
Wrist pitch (pivot)	109° range	120° range	NA	NA	180° range
Wrist roll (rotate)	NA	360° continuous	360° continuous	360° continuous	360° continuous
Temperature	70°F operating	-12°C to 50°C	-12°C to 50°C	-12°C to 50°C	-12°C to 50°C
Tolerance to water	100% humidity	100 ft underwater	100 ft underwater	5,000 ft underwater	100 ft underwater
Accumulated radiation	Not supplied	10 ⁷ rad	10 ⁷ rad	No rad option	10 ⁷ rad
Arm height at full extension (in.)	Not supplied	11.7	4.8	8.2	11.2
Arm width at full extension (in.)	15.55	11.3	4.8	4.8	10.7
Jaw closure force (lb)	88,215	1,000 (estimated)	200	1000	1000
Jaw tong (in.)	22.2	6.0 and 12.0	3	6.0 and 12.0	3.9 and 6.0
Wrist torque (ft•lbf)	NA	90	20	100	100
Cost Estimates					
Manipulator	\$60,000 ^a	\$106,500 ^a	\$84,500 ^a	\$32,500 ^a	\$187,500 ^a
Controller	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
Supplier Chose to Review Data	Yes	Yes	Yes	Yes	Yes

TABLE 2 (Cont.)

Specification	Supplier and Name of Manipulator				
	Kraft TeleRobotics: Grips Force Feedback Manipulator (figure not supplied)	Kraft TeleRobotics: Grips II Force Feedback Manipulator (figure not supplied)	Kraft TeleRobotics: Haz-Trak Force Feedback Manipulator (figure not supplied)	Kraft TeleRobotics: Joystick Rate Manipulator (figure not supplied)	Kraft TeleRobotics: Nine-Function Manipulator (figure not supplied)
Weight (lb)	130	150	2,800	130	164
Maximum reach (in.)	51	54	192	66	69
Degrees of freedom	6 plus grip	6 plus grip	6 plus grip	6 plus grip	8 plus grip
Maximum payload at full extension (lb)	100	100	1,600	100	120
Boom	NA	NA	NA	NA	NA
Shoulder azimuth yaw	180° range	180° range	140° range	120° range	120° range
Shoulder pitch (pivot)	120° range	120° range	110° range	120° range	120° range
Shoulder roll (rotate)	NA	NA	NA	190° range	200° range
Elbow pitch (pivot)	110° range	110° range	100° range	120° range	110° range
Wrist yaw (side pivot)	105° range	200° range	180° range	190° range	115° range
Wrist pitch (pivot)	100° range	200° range	135° range	190° range	115° X 2 range
Wrist roll (rotate)	360° range	360° range	360° range	360° range	360° range
Temperature	0° to 150°F	0°F to 150°F	0°F to 150°F	0°F to 150°F	0°F to 150°F
Tolerance to water	8,000 ft underwater	8,000 ft underwater	95% humidity	8,000 ft underwater	8,000 ft underwater
Accumulated radiation	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
Arm height at full extension (in.)	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
Arm weight full extension (in.)	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
Jaw closure force (lb)	200	200	880	200	200
Jaw tong (in.)	4	4	24	4	4
Wrist torque (ft•lbf)	16	60	740	30	30
Cost Estimates					
Manipulator	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
Controller	Not supplied	Not supplied	Not supplied	Not supplied	Not supplied
Supplier Chose to Review Data	Yes	Yes	Yes	Yes	Yes

TABLE 2 (Cont.)

Specification	Supplier and Name of Manipulator			
	Sarcos: Dextrous Manipulator (figure not supplied)	Sarcos: GRLA Manipulator (figure not supplied)	Western Space and Marine: The Manipulator (figure not supplied)	Western Space and Marine: MK 37 (figure not supplied)
Weight (lb)	53	Not supplied	320	95
Maximum reach (in.)	32.65	72	65	37
Degrees of freedom	7 plus hand	7 plus hand	7	7
Maximum payload at full extension (lb)	40	350	100	50
Boom	NA	NA	Not supplied	Not supplied
Shoulder azimuth yaw	180° range	Not supplied	180° range	180° range
Shoulder pitch (pivot)	180° range	Not supplied	120° range	120° range
Shoulder roll (rotate)	180° range	Not supplied	NA	NA
Elbow pitch (pivot)	180° range	Not supplied	180° range	180° range
Wrist yaw (side pivot)	90° range	Not supplied	115° range	120° range
Wrist pitch (pivot)	180° range	Not supplied	100° range	100° range
Wrist roll (rotate)	180° range	Not supplied	200° range	220° range
Temperature	Not supplied	Not supplied	-20°F to 230°F	-20°F to 230°F
Tolerance to water	Not supplied	Not supplied	Submersible	Submersible
Accumulated radiation	Not supplied	Not supplied	Not supplied	Not supplied
Arm height at full extension (in.)	Not supplied	Not supplied	Not supplied	Not supplied
Arm weight at full extension (in.)	Not supplied	Not supplied	Not supplied	Not supplied
Jaw closure force (lb)	Not supplied	Not supplied	330	250
Jaw tong (in.)	3.5	Not supplied	Not supplied	Not supplied
Wrist torque (ft•lbf)	37.5	Not supplied	Not supplied	Not supplied
Cost Estimates				
Manipulator	Not supplied	Not supplied	\$200,000	\$200,000
Controller	Not supplied	Not supplied	\$100,000	\$100,000
Supplier Chose to Review Data	No	No	Yes	Yes

^a Arm with controller.

FIGURE 2 BM3000 Manipulator, Manufactured by Brokk, North American Sales, Inc.

FIGURE 3 Conan T Manipulator, Manufactured by GEC Alsthom Schilling Robotic Systems, Inc.

FIGURE 4 Hydra T Manipulator, Manufactured by GEC Alsthom Schilling Robotic Systems, Inc.

FIGURE 5 RigMaster Manipulator, Manufactured by GEC Alsthom Schilling Robotic Systems, Inc.

FIGURE 6 Titan III T Manipulator, Manufactured by GEC Alsthom Schilling Robotic Systems, Inc.

TABLE 3 Category RA2 — Specifications of Hydraulically Powered Manipulators ("Near Commercial")

Specification	Supplier and Name of Manipulator	
	Spar Aerospace Limited RMS 2500 Series (see Figure 7)	Spar Aerospace Limited Modified Light Duty Utility Arm System (MLDUA) (see Figure 8)
Weight (lb)	15,000	Arm: 1,500 Total System: 29,500
Maximum reach (ft)	28	15.2 to tool plate; 18.2 including end effector; 37 vertical pos. mast reach
Degrees of freedom	6 plus grip	7 plus gripper
Maximum payload @ full extension (lb)	2,500	200
Boom	See Figure 7	See Figure 8
Shoulder azimuth yaw	$\pm 160^\circ$	$\pm 180^\circ$
Shoulder pitch (pivot)	$+80^\circ$ to -50°	0 to 105°
Shoulder roll (rotate)	NA	NA
Elbow pitch (pivot)	$+50^\circ$ to -80°	Elbow yaw (X2) $\pm 100^\circ$
Wrist yaw (side pivot)	$\pm 160^\circ$	$\pm 100^\circ$
Wrist pitch (pivot)	$\pm 5^\circ$	$\pm 90^\circ$
Wrist roll (rotate)	NA	$\pm 180^\circ$
Temperature ($^\circ\text{F}$)	Operate 70–90 Storage -31–131	Operate 50–150 Storage -20–150
Tolerance to water	5–90% humidity	10–100% humidity
Accumulated radiation	End-effector and wrist — 1.9×10^6 rad; elbow, shoulder, base — 1.1×10^5 rad	2,000 rad/h up to 10^8 rad (minimum 10^6 rad before maintenance)
Arm height @ full extension (in.)	339	See Figure 10
Arm width @ full extension (in.)	334	See Figure 10
Jaw closure force (lb)	80 to 3,200	500
Jaw tong	N/A	N/A
Wrist torque (ft•lbf)	Yaw 833; Pitch 2,083	Roll 58; Pitch 2,000; Yaw 583
Cost Estimates		
Manipulator with controller	Not supplied	Not supplied
Supplier Chose to Review Data	Yes	Yes

FIGURE 7 RMS 2500 Series Manipulator, Manufactured by Spar Aerospace Limited

FIGURE 8 MLDUA Manipulator, Manufactured by Spar Aerospace Limited

TABLE 4 Category RA1 — Specifications of Electrically Powered Manipulators (Commercially Available)

Specification	Supplier and Name of Manipulator			
	AEA Technology:	AEA Technology:	AEA Technology:	AEA Technology:
	N460 (figure not supplied)	N660 (figure not supplied)	N760NM (figure not supplied)	N860 (figure not supplied)
Weight (lb)	31.8	72.7	268.2	218.2
Maximum reach (in.)	49.2	60	59.5	85.6
Degrees of freedom	6 plus grip	6 plus grip	6 plus grip	6 plus grip
Maximum payload at full extension (lb)	22	62	55	220
Shoulder azimuth yaw	NA	NA	NA	NA
Shoulder pitch (pivot)	230° range	230° range	220° range	180° range
Shoulder roll (rotate)	320° range	320° range	320° range	320° range
Elbow pitch (pivot)	250° range	250° range	270° range	220° range
Wrist yaw (side pivot)	NA	NA	NA	NA
Tool roll (rotate)	540° range	540° range	532° range	360° range
Wrist pitch (pivot)	240° range	240° range	200° range	220° range
Wrist roll (rotate)	320° range	320° range	532° range	360° range
Temperature (°C)	0-50	0-40	5-40	0-50
Tolerance to water	Non-condensing	Non-condensing	50% humidity at 40°C	Non-condensing
Accumulated radiation (MGy)	1	1	1	1
Arm height at full extension (in.)	Not supplied	Not supplied	Not supplied	Not supplied
Arm width at full extension (in.)	Not supplied	Not supplied	Not supplied	Not supplied
Jaw closure force (lb)	Not supplied	Not supplied	Not supplied	Not supplied
Jaw tong (in.)	Not supplied	Not supplied	Not supplied	Not supplied
Wrist torque	Not supplied	Not supplied	Not supplied	Not supplied
Cost Estimates				
Manipulator	Not supplied	Not supplied	Not supplied	Not supplied
Controller	Not supplied	Not supplied	Not supplied	Not supplied
Supplier Chose to Review Data	No	No	No	No

TABLE 4 (Cont.)

Specification	Supplier and Name of Manipulator			
	GEC Alstrom Schilling: Helios (see Figure 12)	PaR Systems: 3350 (see Figure 9)	PaR Systems: 4350 (see Figure 10)	PaR Systems: 6350 (see Figure 11)
Weight (lb)	300	350	450	850
Maximum reach (in.)	72	98	112	121
Degrees of freedom	6 plus grip	6 plus grip	6 plus grip	6 plus grip
Maximum payload at full extension (lb)	150	150	250	500
Shoulder azimuth yaw	NA	NA	NA	NA
Shoulder pitch (pivot)	240° range	210° range	210° range	210° range
Shoulder roll (rotate)	540° range	370° range	370° range	370° range
Elbow pitch (pivot)	240° range	240° range	240° range	240° range
Wrist yaw (side pivot)	NA	180° range	180° range	180° range
Forearm roll (rotate)	540° range	NA	NA	NA
Wrist pitch (pivot)	240° range	300° range	300° range	300° range
Wrist roll (rotate)	360° continuous	360° cont.	360° cont.	360° continuous
Temperature (°C)	40	0-45	0-45	0-45
Tolerance to water	Underwater 100 ft	100% humidity max	100% humidity max	100% humidity maximum
Accumulated radiation	10 ⁷ rad	10 ⁸ rad	10 ⁸ rad	10 ⁸ rad
Arm height at full extension (in.)	13.5	9.25	10.5	11.5
Arm width at full extension (in.)	13.5	10.25	10.25	24.5
Jaw closure force (lb)	200	0-500	0-500	0-500
Jaw tong (in.)	4	5 and 8	5 and 8	5 and 8
Wrist torque (lbf)	150	Not supplied	Not supplied	Not supplied
Cost Estimates				
Manipulator	\$300,000 ^a	\$171,000	\$182,000	\$193,000
Controller	Not supplied	\$85,000	\$85,000	\$85,000
Supplier Chose to Review Data	Yes	Yes	Yes	Yes

^a Manipulator with controller.

FIGURE 9 Model 3350 Manipulator, Manufactured by PaR Systems, Inc.

FIGURE 10 Model 4350 Manipulator, Manufactured by PaR Systems, Inc.

FIGURE 11 Model 6350 Manipulator, Manufactured by PaR Systems, Inc.

end-effectors may have to be reviewed and possibly modified for particular applications. Some end-effectors are wrist-held and others are gripper-held. There are also universal end-effector interfaces for using multiple end-effectors. Table 7 lists the types and costs of end-effectors provided by several suppliers.

2.2.2 Other End-Effectors

Special end-effectors or tools (those not listed as standard) have been developed. These end-effectors have been customized for the special applications listed below.

- Autogenous welding (without filler wire)
- Closed circuit television — CCTV (viewing)
- Chisels (pneumatic)
- Electrical discharge machining (EDM) — for metal sampling
- Grinders/abrasive wheels
- Hydraulic torque wrench

FIGURE 12 Helios Manipulator — Manufactured by GEC Alsthom Schilling Robotic Systems, Inc.

- Liquid penetrant examination (PT)
- Ultrasonic examination (UT)
- Mapping digitizer
- Marking
- Molding
- Oxy-fuel torches
- Plasma torches (underwater or in air with 0°–90° nozzles)
- Pneumatic torque/impact wrenches
- Screwdrivers
- Shears (hydraulic)
- Vacuum cleaning
- Welding (with filler wire)

TABLE 5 Category RA2 — Specifications of an Electrically Powered Manipulator ("Near Commercial")

Selection	Omniview, Inc. TeleMate Manipulator (see Figure 13)
Weight (lb)	92.41
Maximum reach (in.)	43.3
Degrees of freedom	6 plus grip
Maximum payload at full extension (lb)	33
Shoulder azimuth yaw	NA
Shoulder pitch (pivot)	$\pm 90^\circ$
Shoulder roll (rotate)	$\pm 45^\circ$
Elbow pitch (pivot)	$+160^\circ, -50^\circ$
Wrist yaw (side pivot)	$\pm 180^\circ$
Wrist pitch (pivot)	$+45^\circ, -120^\circ$
Wrist roll (rotate)	$\pm 180^\circ$
Temperature ($^\circ\text{C}$)	100
Tolerance to water	100% humidity
Accumulated radiation (rad)	10^6
Arm height at full extension (in.)	12
Arm width at full extension (in.)	19
Jaw tong (in.)	3.5
Wrist torque (ft•lbf)	2
Cost Estimate	
Manipulator with controller	\$500,000
Supplier Chose to Review Data	Yes

FIGURE 13 TeleMate Manipulator, Manufactured by Omniview, Inc.

TABLE 6 Features of Controllers

Supplier	Features
AEA Technology	Industrial robotic controller
Brokk	Handheld control box with joysticks Hydraulic control valves Operator always in loop Visually or remote CCTV viewed
Deneb Robotics, Inc.	Dedicated arm controller
GEC Alsthom Schilling Robotic Systems, Inc.	Teach/repeat Force feedback option Microprocessor/control station Remote server driver Enclosed wiring and embedded hydraulics Operator-in-loop or programmed motion Virtual Motion Environment-based operation option Visually or remote CCTV viewed
Kraft TeleRobotics	Dedicated arm controller
Omniview, Inc.	Teach/repeat
PaR Systems, Inc.	Teach/repeat Force feedback option Control console Operator-in-loop or programmed motion Modular controller Remote motor control center Self-diagnostics Touch screen option Visually or remote CCTV viewed
Sarcos Inc.	Replica master arm
Spar Aerospace Limited	Handheld control box Hydraulic control valves Control panel selects modes of manual or computer control Software for programmed trajectories Operator-in-loop or programmed motion Visually or remote CCTV viewed
Western Space and Marine	Force feedback option Microprocessor/control station Remote server driver Operator-in-loop of programmed motion Visually or remote CCTV viewed

TABLE 7 Standard End-Effectors

Supplier	Type	Cost Estimate (\$)
AEA Technology	Gripper-held:	
	NEATER jaw (pneumatic gripper)	Not supplied
	Power drill (in-line or 90°)	Not supplied
	Vacuum gripper	Not supplied
	ARTISAN jaw (hydraulic gripper)	Not supplied
	Reciprocating saw	Not supplied
	Light-duty cropper (shear)	Not supplied
AECL Technologies	Wrist-held:	
	Wet replication tool (contaminated metal sampling)	Not supplied
	Pressure tube sampling tool	Not supplied
	SLAR (spacer location and repositioning) tool	Not supplied
Brokk	Wrist-held:	
	Hydraulic hammer (boulder-breaking)	22,250
	Hydraulic hammer (rock scaling)	22,250
	CC400 concrete-crushing jaw	19,250
	CC550 concrete-crushing jaw	22,500
GEC Alsthom Schilling Robotic Systems, Inc.	Interface-held:	
	Parallel jaw	13,000 ^a
	Claw tool	19,500
	Weld location marking tool	150,000
	Touch probe	6,500
	Air blower	11,000
	Heat gun	14,500
	Suction tool	7,500
	Moisture/instrument probe	9,000
	Spray tool	10,000
	Rotary power tool, 90° drill head	19,000
	Snips (shear)	12,000
	Rotary power tool, in-wire brush	7,500
	Tool rack	Not supplied
	Tool interchange interface	69,000

TABLE 7 (Cont.)

Supplier	Type	Cost Estimate (\$)
PaR Systems, Inc.	Interface-held:	
	Plasma torch	
	Router (8 electric)	26,000
	Vacuum-collection system	32,000
	Circular saw	18,000
	Pipe cutter	4,800
	Wrist rotate and gripper	6,200
	Abrasive saw	14,000
	Grinding tool	5,700
	Nut splitter	5,700
	Bolt cutter	5,700
	Tool rack	5,700
	EOA quick disconnect	11,000
		4,200
Sarcos, Inc.	Wrist-held:	
	Dextrous Hand	Not supplied
	(16 degrees of freedom, 3 fingers, 1 thumb)	Not supplied
	Morph Hand (parallel jaw gripper plus 2 degrees of freedom, thumb)	

^a Included with standard system.

2.2.3 Universal End-Effector Interfaces

Of the suppliers that provide standard end-effectors, three also provide a universal end-effector interface:

- AEA Technology.
- GEC Alsthom Schilling Robotic Systems, Inc.
- PaR Systems, Inc.

Three other companies that provide end-effector (tool) changing systems were found:

- Products for Automation (PFA).
- Robotic Accessories.
- Techno Sommer Automatic.

A universal end-effector interface may be important in some applications for remotely exchanging tools. The services (electrical, hydraulic, pneumatic, etc.) required for remotely attaching and detaching the end-effector to the arm are integrated with the interface plate. Services for the proper functioning of the end-effector may feed through the interface plate or they may be attached directly to the end-effector. A tool rack is usually required when multiple tools are used. Interface plate connectors may include such services as pneumatic supply/return, hydraulic supply/return, electric power (AC or DC), electric ground, signal output/return, and coaxial cable. Other services can be included for custom applications.

2.3 DELIVERY SYSTEM INFORMATION

2.3.1 Suppliers Contacted and Categories

As mentioned previously, the focus for delivery systems is on masts, overhead cranes, and gantries. As information was gathered, it became apparent that delivery systems are not as standardized as manipulators. Masts, cranes, and gantries are usually designed and built for a specific task (e.g., lifting capacity, bridge span, travel distance, and head room).

Argonne contacted 32 suppliers listed in Appendix B to determine if they had commercially available cranes or gantries that could be used as delivery systems for manipulators. After the information provided by the suppliers was reviewed, categories that describe the delivery-system industry were developed. The categorization and distribution of suppliers is shown in Table 8. Several suppliers provide equipment in more than one category. The suppliers for categories CG1 through CG5 are listed below.

CG1 Design and Build: Full Range

American Crane & Equipment Corp., Douglassville, PA
 Ederer, Inc., Seattle, WA
 Harnischfeger, Milwaukee, WI
 IMPSA International, Inc., Pittsburgh, PA (Argentina)
 Whiting Corporation, Harvey, IL
 Zenar, Oak Creek, WI

TABLE 8 Categorization and Description of Suppliers of Crane/Gantry Equipment

Category	Description	Number of Suppliers
CG1	Design and build cranes or gantries for a full range of lifting capacities on the basis of experience and industry standards	6
CG2	Design and build cranes or gantries up to a 50-ton-lifting capacity on the basis of experience and industry standards	5
CG3	Provide a standard product line of adjustable hydraulic jack gantries that can be customized	2
CG4	Provide a standard product line of special-use cranes, gantries, or related equipment that can be customized for an application	4
CG5	Provide such devices as booms or lifts that are commercially available	8
CG6	Do not have applicable equipment	10

CG2 Design and Build: Up to 50 Tons

Abell-Howe, Forest Park, IL
 AEA Technology, Pittsburgh, PA (United Kingdom)
 The Bartholomew Co., Inc., Westbury, NY
 PaR Systems, Inc., Shoreview, MN
 Stock Equipment Co., Chagrin Falls, OH

CG3 Hydraulic Jack Gantries

4 Point Lift Systems, Moline, IL
 J & R Engineering, Big Bend, WI

CG4 Standard Product: Special Use

B.E. Wallace Products Corp., Frazer, PA
 Flow International, Kent, WA

Mi-Jack, Hazelcrest, IL
 Zimmerman Handling Systems, Madison Heights, MI

CG5 Booms and Lifts

Brokk, Seattle, WA (Sweden)
 4 Point Lift Systems, Moline, IL
 Grove Worldwide, Shady Grove, PA
 J & R Engineering Company, Inc., Big Bend, WI
 Mi-Jack, Hazelcrest, IL
 RedZone Robotics, Inc., Pittsburgh, PA
 Resource Services International, Cleveland, OH
 Western Space and Marine, Santa Barbara, CA

2.3.2 Delivery System Types

2.3.2.1 Crane/Gantry

A crane can serve as an overhead X-, Y-, and Z-axes delivery system for a manipulator. One type of crane used for these applications is called a bridge crane. A bridge spans parallel rails and provides the X and Y motion for a trolley. A cable hoist or telescoping mast provides Z-axis motion. Lifting capacities can vary from light loads to 800 tons or more. Bridge cranes are usually ordered and designed for specific applications. Lifting capacity, bridge span, runway length, and lift height are specified. Figure 14 shows the configuration of a typical bridge crane.

A gantry may also provide an overhead delivery system for a manipulator, except only the Y and Z axes are overhead. The gantry frame rides on rails at grade elevation and provides the X-axis motion. A trolley provides the Y-axis motion, and a cable hoist or telescoping mast provides the Z-axis motion. Because gantries do not have to rely on the strength of the building, lifting capacity can vary from light loads to over 2,000 tons. Gantries are more standardized than cranes, but many are ordered and designed for specific applications. Lifting capacity, frame span, runway length, and lift height are specified. Figure 15 shows the configuration of a typical gantry.

The data for the types of cranes/gantries provided by the suppliers in Categories CG1 through CG4 are presented in Tables 9–12. Cost estimates provided by suppliers for a bridge-crane delivery system measuring 25 ft wide × 30 ft long × 25 ft high with a 2 ton lifting capacity and a telescoping mast varied between \$400,000 and \$1,000,000. A cost estimate provided by a different supplier for a similar gantry delivery system was \$450,000.

FIGURE 14 Typical Configuration of a Bridge Crane

2.3.2.2 Booms and Lifts

Another option for a manipulator delivery system is booms or boom cranes. Booms are often referred to as "cherry pickers." The main component of a boom is the three- or four-part telescoping mast, which is connected to a vehicle or a platform. Vehicles can be of a rubber-tired or tractor-crawler design. Lifting capacity can be as much as 150 tons, and the extended height can be up to 173 ft. Figure 16 shows the typical configuration of a boom. The data for the types of booms and lifts provided by the suppliers in Category CG5 are presented in Table 13.

Lifts are similar to a factory fork-lift truck, but they have much greater capacity and maneuverability. The vehicles are usually of a rubber-tired design. Lifting capacity can be as much as 45 tons, and the extended height can be 30 feet. Figure 17 shows the typical configuration of a lift.

2.4 SYSTEM INTEGRATION

Regardless of the delivery system selected, it often has to be integrated with the control of the manipulators. Most delivery system controls are for general positioning, not for the precisely controlled movements required of a manipulator.

FIGURE 15 Typical Configuration of a Gantry

This report has grouped special three-axis transport systems often used by robotics manufacturers with industrial cranes and gantries. Construction and performance characteristics may vary greatly. Industrial cranes are usually not designed for precision position control, but they could be modified for a specific application. If a manipulator is attached to the end of a three-axis positioner, the motion of the two devices may have to be coordinated to provide continuous end-effector control. Many applications will not, however, require simultaneous operation of the manipulator and delivery system, thereby simplifying control requirements. Often, as the complexity and sophistication of a robotic system increases, its reliability and availability decrease. For reactor decommissioning activities, reliability is usually more important than finesse.

TABLE 9 Category CG1 Crane/Gantry Equipment — Design and Build: Full Range

Company	Lifting Capacity (ton)			Bridge Crane	Gantry	Polar Crane	Mono-rail Crane	Jib Crane	Telescoping Mast with Manipulator Experience	Design for Nuclear Decontamination	Supplier Chose to Review Data
	<50	>50	Maximum								
American Crane	Yes	Yes	200	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
The Bartholomew Co.	Yes	Yes	200	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ederer	Yes	Yes	700	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Harnischfeger	Yes	Yes	NS ^a	Yes	Yes	NS	NS	NS	Yes	No	No
IMPSA	Yes	Yes	750	Yes	Yes	Yes	No	No	No	No	Yes
Whiting	Yes	Yes	700	Yes	Yes	Yes	No	No	Yes	No	Yes
Zenar	Yes	Yes	200	Yes	Yes	No	Yes	Yes	No	No	Yes

^a NS = not supplied.

TABLE 10 Category CG2 Crane/Gantry Equipment — Design and Build: Up to 50 Tons

Company	Bridge Crane	Gantry	Polar Crane	Mono-rail Crane	Jib Crane	Telescoping Mast with Manipulator Experience	Design for Nuclear Decontamination	Supplier Chose to Review Data
Abell-Howe	Yes	Yes	No	Yes	Yes	No ^c	No	Yes
AEA Technology	Yes	Yes ^a	No	No	No	Yes	Yes	No
PaR Systems	Yes ^a	Yes	Yes	Yes	No	Yes	Yes	Yes
Stock Equipment	Yes ^b	No	No	No	No	No	Yes	Yes

^a Supplier refers to these as robotic gantries, but they are essentially gantries.

^b Only designed for grappling drums and canisters.

^c Produces telescoping mast but has no experience with manipulators.

TABLE 11 Category CG3 Crane/Gantry Equipment — Hydraulic Jack Gantries

Company	Lifting Capacity (ton)			Bridge Crane	Gantry	Polar Crane	Mono-rail Crane	Jib Crane	Telescoping Mast with Manipulator Experience	Design for Nuclear Decontamination
	<50	>50	Maximum							
4 Point Lift System	Yes	Yes	2,000	No	Yes	No	No	No	No	No
J & R Engineering	Yes	Yes	900	No	Yes	No	No	No	No	Yes

TABLE 12 Category CG4 Crane/Gantry Equipment — Standard Product: Special Use^a

Supplier	Lifting Capacity (ton)			Bridge Crane	Gantry	Polar Crane	Mono-rail Crane	Jib Crane	Telescoping Mast with Manipulator Experience	Design for Nuclear Decontamination
	<50	>50	Maximum							
B.E. Wallace	Yes	No	No supplied	No	Yes ^c	No	No	Yes ^c	No	No
Flow	Yes	No	Not supplied	Yes ^b	No	No	No	No	No	No
Mi-Jack	Yes	Yes	75	No	Yes ^d	No	No	No	No	No
Zimmerman	Yes	No	Not supplied	No	No	No	No	No ^e	No	No

^a These Standard Products can often be modified or customized.

^b Used for positioning cutting apparatus and not for lifting.

^c Manually powered and operated.

^d Provide rubber-tired gantries only.

^e Provide cable/drum hoists only.

FIGURE 16 Typical Configuration of a Boom

FIGURE 17 Typical Configuration of a Lift

TABLE 13 Category CG5 Crane/Gantry Equipment — Booms and Lifts

Company	Maximum ^a Lifting Capacity (tons)	Maximum Boom Length (ft)	Boom	Lift	Maximum Lift Height (ft)
Brokk	0.85	13	-- ^b	-- ^b	16
4 Point Lift Systems	75	45	Yes	No	NA ^d
Grove Worldwide	150	173	Yes	No	NA
J&R Engineering Co.	60	25	-- ^b	-- ^b	34
MI-JACK	45	NA	No	Yes	30
RedZone Robotics, Inc.	1 ^c	20	Yes	No	NA
Resource Services Int'l.	1.5 ^c	30	-- ^b	-- ^b	8
Western Space and Marine	10	24	-- ^b	-- ^b	30

^a Not at full extension.

^b This is a boom and lift combination.

^c At full extension.

^d Not Applicable.

3 BIBLIOGRAPHY

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2. *Nuclear News Buyers Guide*, 1995, American Nuclear Society 38(4), LaGrange Park, IL, March.
3. *Nuclear Plant Journal Product & Services Directory — 1995 Issue*, 1994, EQES, Inc., 12(6), Glen Ellyn, IL, November.
4. Tosunoglu, S., 1994, *Robotics Technology Assessment for Decontamination and Dismantlement Tasks*, U.S. Department of Energy, Office of Technology Development, Robotics Technology Development Program, University of Texas at Austin, Austin, TX, August.

APPENDIX A:
MANIPULATOR SUPPLIERS

APPENDIX A: MANIPULATOR SUPPLIERS

TABLE A.1 Categories Used to Describe Robotic Arms

Category	Description
RA1	Commercially available manipulators w/controls
RA2	Provided a manipulator several times ("near commercial")
RA3	Develop unique manipulators for an application
RA4	Purchase manipulators and package them for an application
RA5	Provide crawlers or ROVs
RA6	Provide manipulator controls only
RA7	None of the above

Categories are included in the suppliers listed in this appendix.

AEA Technology
 241 Curry Hollow Road
 Pittsburgh, PA 15236-4696
 Contact: Tim Boorman
 (412) 655-1200
 FAX: (412) 655-2928
 Category: RA1

Applied Radiological Control (ARC)
 500 Chastain Center Blvd.
 Kennesaw, GA 30144-59999
 Contact: Ted Martucci
 (800) 241-6575
 FAX: (404) 428-3090
 Category: RA7

AECL Technologies
 9210 Corporate Blvd.
 Rockville, MD 20850
 Contact: Phil Campbell or Dave McDougall
 (800) 872-2325
 FAX: (301) 417-0746
 Category: RA3, RA5

ARD Environmental Corporation
 9151 Rumsey Road
 Columbia, MD 21045-1929
 Contact: Mark Thomas
 (800) 241-6575
 FAX: (410) 997-3902
 Category: RA5

ASI Robotic Systems
1250 Crooks Road
Clawson, MI 48017
(313) 288-5070
FAX: (313) 435-3525
Category: RA3

B&W Nuclear Technologies
P.O. Box 10935
Lynchburg, VA 24506-0935
Contact: Dennis Williams
(800) 231-3628
FAX: (804) 932-2621
Category: RA7

The Bartholomew Co., Inc.
91 New York Ave.
Westbury, NY 11590
Contact: Harry G. Gotte III
(516) 333-0100
FAX: (516) 333-0301
Category: RA4

Benthos, Inc.
49 Edgerton Drive
North Falmouth, MA 02556
Contact: Kevin McCarthy
(800) 446-1222
FAX: (508) 563-6444
Category: RA5

BNFL, Inc.
1835 Terminal Drive, Suite 220
Richland, WA 99352
Contact: Maurice Bullock
(509) 946-4006
FAX: (509) 946-4852
Category: RA1

Brokk, North American Sales, Inc.
1144 Village Way
Monroe, WA 98272
Contact: Mike Martin
(800) 621-7856
FAX: (206) 487-2963
Category: RA1, RA5

Brooks Support Systems Inc.
6546 Pound Road
Williamson, NY 14589
Contact: Frank Dickey
(800) 836-0285
FAX: (315) 589-4089
Category: RA7

Central Research Laboratories
250 Hwy. 19
Red Wing, MN 55066
Contact: Laurie Brown
(612) 385-2142
FAX: (612) 388-1232
Category: RA7

Cybermotion, Inc.
115 Sheraton Drive
Salem, VA 24153-3003
Contact: Celeste DeCorte
(703) 562-7626
FAX: (703) 562-7632
Category: RA5

Deepsea Power & Light Co.
4819 Ronson Ct.
San Diego, CA 92111
Contact: Bob Novak
(619) 576-1261
FAX: (619) 576-0219
Category: RA7

Deneb Robotics, Inc.
 3285 Lapeer Road West
 P.O. Box 214687
 Auburn Hills, MI 48321-4687
 Contact: Brian Christenson
 (810) 377-6900
 FAX: (810) 377-8125
 Category: RA6

EPRI
 1300 Harris Blvd.
 Charlotte, NC 28221
 Contact: Ken Brittain
 (704) 547-6139
 FAX: (704) 547-6168
 Category: RA7

Foster-Miller, Inc.
 350 Second Ave.
 Waltham, MA 02154-1196
 Contact: Michael Reinhart
 (617) 890-3200
 FAX: (617) 890-8515
 Category: RA5

GE Nuclear Energy
 175 Curtner Ave.
 San Jose, CA 95125
 Contact: Steve Barber
 (408) 925-1151
 FAX: (408) 925-1148
 Category: RA7

GEC Alsthom Schilling Robotic
 Systems, Inc.
 1632 DaVinci Court
 Davis, CA 95616
 Contact: Wes Gerriets or Tyler Schilling
 (916) 753-6718
 FAX: (916) 753-8092
 Category: RA1

General Atomics
 P.O. Box 85608
 San Diego, CA 92186-9784
 Contact: Jim McNair
 (619) 455-2802
 FAX: (619) 455-2110
 Category: RA4

Grove Worldwide
 1565 Buchanan Trail East
 P.O. Box 21
 Shady Grove, PA 17256-0021
 Contact: Traci Hahn
 (717) 597-8121
 FAX: (717) 597-4062
 Category: RA5

Kraft TeleRobotics
 11667 West 90th Street
 Overland Park, KS 66214
 Contact: Steve Harbur
 (913) 894-9022
 FAX: (913) 894-1363
 Category: RA1, RA5

NAC International
 655 Engineering Drive
 Norcross, GA 30092-2813
 Contact: Gary Tjersland
 (800) 241-0507
 FAX: (404) 447-1797
 Category: RA4

NES, Inc.
 44 Shelter Rock Road
 Danbury, CT 06810-7095
 Contact: Jim Hedtke
 (203) 796-5273
 FAX: (203) 796-3168
 Category: RA4

NSS Numanco, Inc.
 West Market Street
 Campbelltown, PA 17010
 Contact: Fred Erskine
 (800) 338-7333
 FAX: (717) 838-8400
 Category: RA7

Nuclear Systems Associates (NSA)
 2741 Saturn Street
 Brea, CA 92621
 Contact: Bill Thompson
 (714) 996-4670
 FAX: (714) 996-4712
 Category: RA3

NUS
 910 Clopper Road
 Gaithersburg, MD 20878-1399
 Contact: Frank Gallo
 (800) 368-2755
 FAX: (301) 258-8764
 Category: RA4

Oceaneering Technologies
 501 Prince George Blvd.
 Upper Marlboro, MD 20772
 Contact: Andrew Resnick
 (301) 249-3300
 FAX: (301) 249-4022
 Category: RA4

Odetics
 1515 South Manchester
 Anaheim, CA 92802-2907
 Contact: Thomas Bartholet
 (714) 780-7805
 FAX: (714) 780-7857
 Category: RA3

Omniview, Inc.
 7325 Oak Ridge Highway
 Knoxville, TN 37921
 Contact: Brad Hobbs or Dan Kuban
 (423) 690-5600
 FAX: (423) 690-2913
 Category: RA2

PaR Systems
 899 Highway 96 West
 Shoreview, MN 55126
 Contact: Albert J. Sturm, Jr.
 (612) 484-7261
 FAX: (612) 483-2689
 Category: RA1

Pentek Decontamination Products Div.
 1026 Fourth Ave.
 Coraopolis, PA 15108
 Contact: Eric Crivella
 (412) 262-0725
 FAX: (412) 262-0731
 Category: RA7

Products for Automation (PFA)
 15885 W. Overland Drive
 New Berlin, WI 53151
 Contact: Julie A. Hoaglan
 (414) 785-1869
 FAX: (414) 785-9161
 Category: RA7

PLS International
 10910 Briggs Road
 Cleveland, OH 44111
 Contact: Dale Vandervort
 (216) 252-7700
 FAX: (216) 252-7792
 Category: RA4

RedZone Robotics, Inc.
 2425 Liberty Avenue
 Pittsburgh, PA 15222-4639
 Contact: Leona Bares
 (412) 765-3064
 FAX: (412) 765-3069
 Category: RA4

Resource Services International
 6001 Breakwater Avenue
 Cleveland, OH 44102
 Contact: Harold C. Pedersen
 (216) 651-2550
 FAX: (216) 651-6811
 Category: RA4

Reinhart & Associates
 P.O. Box 9802
 Austin, TX 78766
 Contact: Louis Strange
 (800) 553-5498
 FAX: (512) 834-1266
 Category: RA7

Remote Systems Services
 1800 Freeway Blvd.
 Minneapolis, MN 55430-1747
 Contact: Glenn McKeag
 (612) 484-7261
 FAX: (612) 561-4827
 Category: RA7

Remotec
 114 Union Valley Road
 Oak Ridge, TN 37830
 Contact: Brad Callahan
 (423) 483-0228
 FAX: (423) 483-1426
 Category: RA5

Robotic Accessories
 6555 State Route 202
 Tripp City, OH 45371
 Contact: Anjela Janowiecki
 (513) 667-5705
 FAX: (513) 667-7602
 Category: RA7

R.O.V. Technologies
 P.O. Box 10
 Georges Mill, Rte. 142
 Vernon, VT 05354-0010
 Contact: Troy Dennen
 (802) 254-9353
 FAX: (802) 254-9354
 Category: RA5

Rust Utility Services
 P.O. Box 699
 110 Plains Road
 Essex, CT 06426
 Contact: John Allanach
 (800) 872-6827
 FAX: (203) 767-0612
 Category: RA4

Sarcos Inc.
 360 Warkara Way
 Salt Lake City, UT 84108
 Contact: Dave Salmon
 (801) 581-0155
 FAX: (801) 581-1151
 Category: RA1

Silma
 1601 Saratoga-Sunnyvale Rd.
 Cupertino, CA 95014
 Contact: Lisa Lambro
 (800) 347-4562
 FAX: (408) 725-8955
 Category: RA6

Spar Aerospace Limited
 30 Tower Lane
 Avon Park South
 Avon, CT 06001
 Contact: Peter Kruse
 (203) 674-1295
 FAX: (203) 678-1862
 Category: RA2, RA5

Stenning Instruments
 604 Via Del Cerro
 Camarillo, CA 93010-8439
 Contact: Lola Stenning
 (805) 484-4996
 FAX: (805) 484-5337
 Category: RA7

Stock Equipment Co.
 16490 Cillicothe Rd.
 Chagrin Falls, OH 44023-4398
 Contact: Tom Litchney
 (800) 289-7326
 FAX: (216) 543-5944
 Category: RA7

Techno Sommer Automatic
 2101 Jericho Turnpike
 New Hyde Park, NY 11042-5416
 (516) 328-3970
 FAX: (516) 326-8827
 Category: RA7

Viking Systems International
 2070 William Pitt Way
 Pittsburgh, PA 15238
 Contact: Jack Saluja
 (412) 826-3355
 FAX: (412) 826-3353
 Category: RA5

Visual Inspection Technologies
 27-2 Ironia Road
 Flanders, NJ 07836-9124
 Contact: Bruce Pellegrino
 (800) 848-5665
 FAX: (201) 927-3207
 Category: RA5

Welding Services, Inc.
 2225 Skyland Court
 Norcross, GA 30071
 Contact: Mike Welch
 (800) 868-9353
 FAX: (404) 449-4684
 Category: RA7

Western Space and Marine
 111 Santa Barbara Street
 Santa Barbara, CA 93101
 Contact: Jeff Millard
 (805) 963-3831
 FAX: (805) 963-3832
 Category: RA1, RA5

Westinghouse
 Waltz Mill Site
 Madison, PA 15663
 Contact: Tom Arzenti
 (412) 722-5845
 Category: RA7

R. W. Wiesener, Inc.
 705 Brunson Drive
 Albermarle, NC 28001
 (704) 982-9242
 FAX: (704) 982-9242
 Category: RA7

APPENDIX B:
CRANE AND GANTRY SUPPLIERS

APPENDIX B:

GRANE AND GANTRY SUPPLIERS

TABLE B.1 Categories Used to Describe Cranes/Gantries

Category	Description
CG1	Design and build: full range
CG2	Design and build: up to 50 tons
CG3	Hydraulic jack gantries
CG4	Standard product line: special use
CG5	Booms and lifts commercially available/customized
CG6	None of the above

Abell-Howe Co.
 7747 Van Buren Street
 Forest Park, IL 60130
 Contact: Tony Pabich
 (708) 366-4800
 FAX: (708) 366-3401
 Category: CG2

Applied Radiological Control
 500 Chastain Center Road
 Kennesaw, GA 30144-5999
 Contact: Ted Martucci
 (800) 241-6575
 FAX: (404) 428-3090
 Category: CG6

AEA Technology
 241 Curry Hollow Road
 Pittsburgh, PA 15236-2928
 Contact: Tim Boorman
 (412) 655-1200
 FAX: (412) 655-2928
 Category: CG2

The Bartholomew Co.
 91 New York Ave.
 Westbury, NY 11590
 Contact: Harry G. Gotte III
 (516) 333-0100
 FAX: (516) 333-0301
 Category: CG2

American Crane & Equipment Corp.
 (ACECO)
 531 Old Swede Road
 Douglassville, PA 19518
 Contact: David Schaeffer
 (610) 385-6061
 FAX: (610) 385-3191
 Category: CG1

B.E. Wallace Products Corp.
 71 Bacton Hill Road
 Frazer, PA 19355
 Contact: Sherry de Carville
 (610) 647-1400
 FAX: (610) 644-9043
 Category: CG4

Brokk
1144 Village Way
Monroe, WA 98272
Contact: Mike Martin
(800) 621-7856
FAX: (206) 487-2963
Category: CG5

Cattron
58 W. Shewago
Pittsburgh, PA 16150
Contact: Brian Ellison
(412) 962-3571
FAX: (412) 962-4310
Category: CG6

Ederer Inc.
2925 First Ave. South
Seattle, WA 98134
Contact: Brian Kennon
(206) 622-4421
FAX: (206) 623-8583
Category: CG1

Flow International
23500 64th Ave.
South Kent, WA 98032
Contact: Mark Fleck
(612) 440-6016
FAX: (206) 813-3285
Category: CG4

4 Point Lift Systems
205 41st Street
P.O. Box 906
Moline, IL 61265
Contact: Bruce Foster
(800) 728-4911
FAX: (309) 764-9848
Category: CG3, CG5

Grove Worldwide
1565 Buchanan Trail East
P.O. Box 21
Shady Grove, PA 17256-0021
Contact: Traci Hahn
(717) 597-8121
FAX: (717) 597-4062
Category: CG5

Harnischweger
P.O. Box 554
Milwaukee, WI 53201
Contact: Ray Greene
(414) 671-4400
FAX: (414) 671-7469
Category: CG1

Hydro-Abrasive Machining Inc.
8831 Miner St.
Los Angeles, CA 9002
Contact: Mike Woolman
(213) 587-1342
FAX: (213) 587-1818
Category: CG6

IMPSA International, Inc.
1910 Cochran Road
Pittsburgh, PA 15220
Contact: Gerald Katz
(412) 344-7003
FAX: (412) 344-7009
Category: CG1

J&R Engineering Company, Inc.
W224 S8535 Industrial Drive
P.O. Box 218
Big Bend, WI 53103
Contact: Roger Johnston
(414) 662-2297
FAX: (414) 662-4039
Category: CG3, CG5

Jervis B. Webb Co.
 34375 West Twelve Mile
 Farmington Hills, MI 48331
 Contact: Paul Hoppersberger
 (810) 553-1220
 FAX: (810) 553-1228
 Category: CG6

Lift Tech Cranes
 4141 W. Broadway
 Muskegon, MI 49444
 Contact: Brian Reed (616) 733-0821
 Bill Cozzens (708) 968-0802
 FAX: (616) 739-7249
 Category: CG6

Mi-Jack
 3111 W. 167th Street
 Hazelcrest, IL 60429
 Contact: Don Fox or Dan Heraty
 (708) 596-5200
 FAX: (708) 225-2312
 Category: CG4, CG5

NES, Inc.
 44 Shelter Rock Road
 Danbury, CT 06810-7095
 Contact: Jim Hedtke
 (203) 796-5273
 FAX: (203) 796-3168
 Category: CG6

PaR Systems, Inc.
 899 Highway 96 West
 Shoreview, MN 55126
 Contact: Albert J. Sturm, Jr.
 (612) 484-7261
 FAX: (612) 483-2689
 Category: CG2

RedZone Robotics, Inc.
 2425 Liberty Avenue
 Pittsburgh, PA 15222-4639
 Contact: Leona Bares
 (412) 765-3064
 FAX: (412) 765-3069
 Category: CG5

Resource Services International
 6001 Breakwater Avenue
 Cleveland, OH 44102
 Contact: Harald C. Pedersen
 (216) 651-2550
 FAX: (216) 651-6811
 Category: CG5

Rigging International
 P.O. Box 4013
 Alameda, CA 94501-1029
 Contact: Jeanette Mungai
 (510) 865-2400
 FAX: (510) 865-9450
 Category: CG6

Stock Equipment Co.
 16490 Chillicothe Road
 Chagrin Falls, OH 44023-4398
 Contact: Tom Litchney
 (800) 289-7326
 FAX: (216) 543-6678
 Category: CG2

2 DM Associates
 7322 Southwest Expressway
 Suite 670
 Houston, TX 77074
 Contact: David Duerr
 (713) 270-5044
 FAX: (713) 270-6139
 Category: CG6

United States Crane Inc.
P.O. Box 593290
Orlando, FL 32859-3290
Contact: Dean German
(407) 859-6000
FAX: (407) 857-9146
Category: CG6

Western Space and Marine
111 Santa Barbara Street
Santa Barbara, CA 93101
Contact: Jess Millard
(805) 963-3831
FAX: (805) 963-3832
Category: CG-5

Whiting Corporation
15700 Lathrop Ave.
Harvey, IL 60426-5198
Contact: Greg Ciecierski
(312) 468-9400
FAX: (708) 210-5030
Category: CG1

Williams Crane & Rigging, Inc.
P.O. Box 1116
Richmond, VA 23208
Contact: Carl Schmidt
(804) 233-9221
FAX: (804) 232-4121
Category: CG6

Zenar
7301 S. 6th Street
Oak Creek, WI 53154
Contact: Bill Kenton
(414) 764-1800
FAX: (414) 764-1267
Category: CG1

Zimmerman Handling Systems
29555 Stephenson Hwy.
Madison Heights, MI 48071-2387
Contact: Steve Calvert
(708) 231-9301
FAX: (810) 398-1374
Category: CG4

APPENDIX C:

GLOSSARY

APPENDIX C: GLOSSARY

Bridge Crane	A crane with a movable bridge that travels on an overhead fixed runway. The bridge supports a fixed or movable trolley that carries the hoisting mechanism.
CCTV	Closed-circuit television.
Computer Control	Use of a computer, with or without human intervention, to control movements and operations of equipment. The computer can be preprogrammed or it can "learn" as an operation is under way.
Commercial	An item offered as a standard item for sale (usually a catalog item).
Degrees of Freedom (DOF)	A direction or dimension of motion in a mechanism, such as wrist rotation or elbow pivot.*
End-Effector	An accessory device or tool specifically designed for attachment to a robot wrist or tool mounting plate to enable the robot to perform its intended task.
Force Feedback	The human operator of the master arm actually feels a portion of the load as sensed by each joint of a robotic arm.
Gantry Crane	A crane similar to a bridge crane, except the bridge for supporting the trolley is supported on two or more legs running on a runway.
Hoist	A machinery unit that is used for lifting or lowering a freely suspended load.
Joystick	A device consisting of a hand-held stick that pivots about one end and transmits to a computer its angle in two dimensions..
Manipulator	Servo-controlled, open-link, series connected, kinematic chains that perform sophisticated 3-D motion.* Manipulators are sometimes referred to as "robotic arms."
Master/Slave	Term generally applied only to the common mechanical and electronic manipulators that have long been used in hot cells. The controls are the master and the actuators are the slave.*

Payload	The weight of an item, including all rigging and hardware, being lifted by a crane or gantry.
Programmable	The ability to cause a manipulator or robotic system to perform a repeatable desired function through the use of a series of predetermined and prerecorded commands.
Remotely Operated	The ability to operate and control a mechanical device from a remote location by either human or computer control.
Robotic Device	A multi-purpose mechanical manipulator capable of performing a sequence of physical tasks without human intervention.
Teach/Learn (Teach/Repeat)	The generation and storage of a series of positional data points affected by moving the manipulator through a path of intended motions.
Telemanipulation	An approach that uses highly dexterous "extended reach tools" and physical barriers between the human and the hazardous environment. Manipulation is often through mechanical master/slave manipulators, and vision is usually through a window or periscope.*
Teleoperation	An approach that uses a general purpose, dexterous, human-machine system that augments a human by projecting his or her manipulatory capabilities across distance and through physical barriers into hostile environments. Typically, manipulation is by movable mechanisms, and vision is through windows, periscopes, or cameras.*
Telerobotics	An approach that uses teleoperation with selectable automation. Some functions are performed without human intervention.*
Virtual Reality	Computer simulations that use 3D graphics and various devices to allow the user to interact with the simulation.

* *Remote Handling Technology: History and State-of-the-Art*, 1987, Oak Ridge National Laboratory, Oak Ridge, TN.

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 Dick Meservey, P.O. Box 1625, Idaho Falls, ID 83415
 Bruce M. Wilding, P.O. Box 1626, Mail Stop 2220, Idaho Falls, ID 83415
 Walter D. (David) Willis, P.O. Box 1626, Mail Stop 2220, Idaho Falls, ID 83415

Quest Integrated, Inc. (QI2)

Edward Bohn, 21414 68th Avenue South, Kent, WA 98032
 Bruce Goldwater, 21414 68th Avenue South, Kent, WA 98032

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Redzone Robotics, Inc.

Leona (Lee) C. Bares, 2425 Liberty Avenue, Pittsburgh, PA 15222-4639
 Lou Conley, 2425 Liberty Avenue, Pittsburgh, PA 15222-4639
 Bruce Thompson, 2425 Liberty Avenue, Pittsburgh, PA 15222-4639

Sandia National Laboratories (SNL)

Brady R. Davies, P.O. Box 5800, Albuquerque, NM 87185-1177

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Daniel S. Horschel, P.O. Box 5800, Albuquerque, NM 87185-1177

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Robert Vagnetti, 1224 Pinview Drive, Morgantown, WV 26505

Westinghouse Savannah River Company

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