# Remotely-Controlled Mobile Manipulator for Use in Radioactive Environments – 10262a

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## ABSTRACT

In the spring of 2009 PaR® Systems developed a new high capacity mobile manipulator for remote applications in highly radioactive environments such as hot cell operations and maintenance, material handling, D&D, reactor outages (e.g. steam generator repair) and other remote activities. The first unit was delivered to Argonne National Laboratory (ANL) for use in their Alpha Gamma Hot Cell Facility (AGHCF). The new manipulator replaced a PaR mobile manipulator that has been in service in the AGHCF since 1964. The original machine, although still operational, is near the end of its useful service life and Argonne had the need for a higher capacity and longer reach manipulator.

## INTRODUCTION

While there are a number of commercially available tracked mobile manipulators on the market, there are none that would meet the unique requirements of the AGHCF manipulator. The Argonne design specifications required that the manipulator be able to reach a height of 3.4m (11 feet), access objects on the floor, and be capable of supporting a 91 kg (200 pound) load at a horizontal distance of 1.2 m (four feet) from the center of the vehicle. Due to the space constraints within the AGHCF the manipulator had to be able to fit through a door opening of 0.7 m (2 ft. 4 in.) wide by 1.9 m (6 ft. 2 in.) high. The vehicle must be capable of towing a 181 kg (400 pound) load with its tow hook and be able to be retrieved from the cell by its tow hook with a maximum force of 68 kg (150 pounds). The manipulator also had to be modular and break down into remotely detachable subassemblies, each with a maximum weight of 227 kg (500 pounds) to facilitate maintenance of the manipulator.

## ALPHA GAMMA HOT CELL FACILITY

Operation of the Alpha Gamma Hot Cell Facility (AGHCF) at Argonne National Laboratory (ANL) has been supported by the U.S. Department of Energy (DOE) since 1964. From 1964 through 2005, the AGHCF was used for conducting research on the behavior of materials, fuel, and structures used in nuclear reactors. The primary goal of this research was to allow for the development of safe and reliable fuel systems for advanced power reactors. A secondary goal was to provide information for the safe future handling of irradiated materials for the protection of the environment. All research and development (R&D) activities ceased in August 2005.

In January 2006, as directed by the DOE, the AGHCF has transitioned from the previous R&D activities to a mission involving radioactive and hazardous material handling, management, storage, and disposition. Current operations involve general material handling and storage, which includes storage of current inventory, as well as support of the ANL site inventory reduction with the receipt and storage of hazardous and radioactive materials from other facilities. Additional operations also include inventory characterization, resizing and volume reduction, and packaging (or repackaging) to support the shipment of materials and equipment out of the facility.

Continued deactivation and decommissioning (D&D) operations are expected for a period of five to ten years. During that time, capabilities to resize and volume reduce and to package (and repackage) in support of the shipment of materials and equipment out of the AGHCF will need to be expanded. The PaR robotic manipulator will be a key element in the support of these activities.

## PAR ROBOTIC MANIPULATOR

The robotic technology utilized in the AGHCF, as well as the equipment employed within it, was state of the art in 1964. Critical in-cell maintenance has been performed by the track driven PaR® 3000 mobile manipulator (robot) since the hot cell started operating. The PaR® 3000 is an AC-powered wire-remote-controlled manipulator which is capable of lifting significant weights of 68 kg (150 lbs) maximum. Operation and control of the robot is achieved from outside the hot cell with a detachable control unit plugged into one of the wall sockets located at various points on the perimeter wall. The robot operates in an atmosphere that is approximately 100% nitrogen and very low humidity levels. Radiation levels fluctuate depending on the configuration of stored radiological material, with exposure varying from levels as high as 50,000 Rad/hour and as low as 1 Rad/hour.

During the years from 1964 through 2005, remote operations in the hot-cell were conducted using Central Research Labs (CRL) through wall master slave manipulators (MSM) installed at 10 of the 12 shielding windows in the cell. One of the principal uses of the robot is to detach the in-cell portions of these CRL MSM's whenever maintenance or repair is required. The robot is then used to re-attach the MSM's (as shown in Figure 1) when those activities are completed. In addition, the robot serves as an all-purpose tool for assisting with repair of other in-cell equipment, replacing HEPA filters, picking up material from hard to reach places (i.e., the hot cell floor, under shelves, etc.)

**Figure 1: PaR® 3000 Hanging MSM**

The 45 year old PaR® 3000 is approaching the end of its useful service life due to age, wear, and component failures. However, continued (D&D) operations are expected to continue for a period of five to ten years. Plans are to keep the PaR® 3000 robot in operation and use it for light-duty applications, and in support of the new PaR® Model TR®4350 In-Cell Robotic Manipulator

## CURRENT AGHCF REQUIREMENTS

The expanded mission of the AGHCF and increased requirements for remote activities in the next five to ten years demand a more robust and higher capacity robot with greater reach and flexibility. The new PaR® TR®4350 robot has that capability and will be expected to perform the same tasks as the PaR® 3000, including using the robot to detach/re-attach the in-cell portions of the current CRL MSM's (which are heavier than the old ones). The new PaR® robot will be employed in conjunction with task-specific equipment that is yet to be introduced into the hot-cell. This equipment will include cutting, shearing and/or drilling units, mobile hoists, etc. that will be required for size reduction of legacy equipment that must be removed from the cell. The larger and more robust PaR® TR®4350 manipulator will be better suited to handle these additional tasks.

## NEW MANIPULATOR DESIGN CHALLENGES

Commercially available mobile robots are typically designed as tracked vehicles capable of traversing across uneven terrain and do not have the lifting capacity or the reach required by ANL. The unique requirements of the AGHCF robot (narrow footprint with high capacity and reach and radiation resistant) required a new crawler vehicle design. PaR® designed the tracked vehicle with a low center of gravity by capitalizing on the relatively smooth floor and minimizing the clearance height. Track belts with idler wheels between the drive wheels were chosen in lieu of a four-wheel arrangement so the vehicle could pass over door thresholds and ramps without bottoming out. The vehicle operates like a skid-steer, allowing the machine to turn on its axis by driving the tracks in opposite directions.

The robot was also designed with modular remotely detachable subassemblies for ease of maintenance operations and to accommodate in-cell lifting capacities. Using in-cell master/slave manipulators, power manipulators and hoists, the manipulator's hand, wrist, arm and telescoping pedestal can all be remotely separated. Both mechanical and electrical connections are made remotely. These modules can then be transferred into the maintenance area for repair or routine maintenance. The manipulator and vehicle separates into 5 modular pieces very readily without the need to remove any fasteners. The modules are secured during operations through the use of toggle clamps, pins or slip collars. Electrical connections are also integrated into the modular design and as each modular section is removed or installed, the electrical connection is disconnected or made (i.e. no separate connections are necessary).

The drive tracks are commercially available belts and are driven by two removable motor/reducer/clutch assemblies; one per side. The clutches engage upon power-up. When power is removed from the robot the clutches disengage allowing the robot to free-wheel for recovery purposes. The drive assemblies can be easily separated from the vehicle for repair or routine maintenance.

The telescoping pedestal mounted to the vehicle has twelve inches of vertical travel and contains a 370° travel shoulder rotate axis. The vertical axis is driven by an Acme lead screw which does not back-drive; therefore when power to the drive motor is removed the vertical position is locked. The shoulder rotate assembly uses a variable speed DC motor coupled to a right angle reducer and cone drive that is slip clutch protected. The pedestal-shoulder assembly is detached from the vehicle (following removal of the manipulator) by pulling three locking pins at the base of the pedestal and lifting it vertically using an in-cell hoist.

The manipulator is PaR's standard Model TR®4350 and includes shoulder, elbow and wrist pivots. The TR®4350 is sealed, uses corrosion resistant materials and finishes, and has internal wiring for easy wash-down and decontamination. A unique torque sharing design allows the shoulder, elbow, and wrist pivot drives to be uniformly sized and located on the shoulder reducing its dead weight. The kinematic design allows positioning of the shoulder and elbow pivot joints without changing the wrist orientation. Power for the pivot motions are transmitted by belts and pulleys. All manipulator pivot, rotate and grip axes are slip-clutch protected to prevent damage to mechanical drive components and motors. Within the rated capacity, motions will not move under load with the power supply off.

The range of motion and speed for each robot axis is shown in Table 1 below. The robot is able to reach objects at a height of 3.5 m (11 ft. 5 in.) from the floor and able to access objects on the floor or under tables or shelves. Figure 2 shows the robot posed at two such positions.

**Figure 2: Robot Range of Reach; 3.5 m (11 ft. 5 in.) to Floor Level**

**Table 1: Robot Range of Motion and Axis Speeds**

| Axis | Range of Motion | Speed |
|---|---|---|
| Crawler | Continuous | 914 cm/min (30 ft/min) |
| Telescoping Pedestal | 0.3 m (12 in.) | 61 cm/min (2 ft/min) |
| Shoulder Rotate | 370º | 1 rpm |
| Shoulder Pivot | 240º | 1 rpm |
| Elbow Pivot | 240º | 1 rpm |
| Wrist Pivot | 300º | 1 rpm |
| Wrist Rotate | Continuous | 7 rpm |
| Wrist Extend | 15 cm (6 in.) | 30 cm/min (1 ft/min) |
| Gripper | 20 cm (8 in.) | 50 cm/min (1.6 ft/min) |

Arm sections are of a box type construction for maximum rigidity. Pivoting surfaces are sealed with O-rings. Access plates in the arms are gasketed to keep the internal components free of debris.

The wrist is a PaR® Model 6000 and has a continuous rotate, six inch extend and parallel jaw grip axes. The wrist assembly can be detached from the manipulator by unlatching two toggle-type latches on the wrist housing. A 115 volt electrical receptacle is mounted it the wrist housing for use with power tools. Tool speed and direction can be controlled from the control console.

Coupling or uncoupling of the hand is accomplished by straight-line motion of the wrist extend which actuates a spring-loaded collar on the wrist when placed in a hand change fixture. Grip force is controlled by an electric clutch. This clutch also provides overload protection. The desired grip force is set remotely by use of a virtual slider bar on the control console.

The manipulator is radiation hardened and designed to operate in an environment of an ionizing radiation field consisting of gamma and beta in excess of 500 Gray/hour continuously for a minimum of five years. Radiation levels in the AGHCF are location dependent and range between 1 and 500 Gray/hour. Materials and commercial components were also selected to withstand harsh chemical decontamination for maintenance and repair.

## MANIPULATOR CONTROL SYSTEM

The manipulator is controlled from outside the hot cell through one of two portable remote control consoles. A color screen on the control console displays control functions, modes of operation and status. Dual joysticks have three axes of motion each. The axis definitions are oriented such that control functions are intuitive as the operator looks into the cell through the viewing windows. See Figure 3 below. Figure 4 shows a screen shot of the controller display.

**Figure 3: Dual-Joystick Control Console**

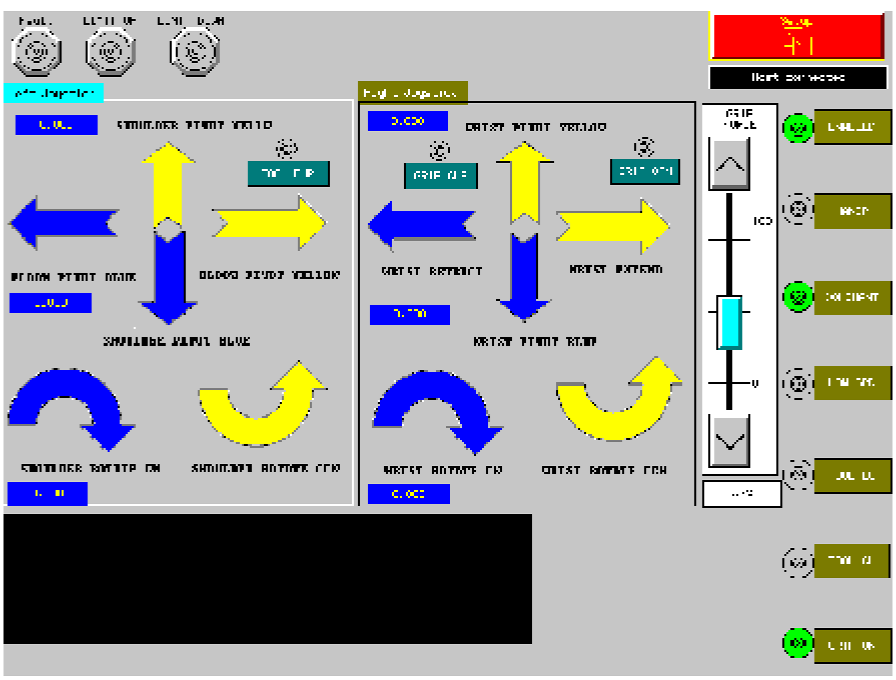

**Figure 4: Controller Display Screen**

The deflection of a joystick is converted into a speed command for the appropriate motor. The joysticks are configured with a dead-band range so that no motion is commanded when the joysticks are released. The manipulator and mast will hold fixed positions any time the joystick affecting a particular operation is released. Continued application of control power is unnecessary to maintain the position.

A separate power center cabinet houses the power supplies and switching equipment for the manipulator system. The source power (240 volts single phase) is brought to the main circuit breaker. Mounted inside of the power center are the motor drives, motor drives power transformer, 12 VDC and 24 VDC power supplies, control relays, PLC and miscellaneous equipment.

## CONCLUSION

Argonne's new Mobile Manipulator will meet the remote handling needs of the Alpha Gamma Hot-Cell Facility from its current mission through the ultimate decommissioning of the cell. The increased lift capacity, long reach arm, ability to handle power tools and optional gripper configurations will give Argonne a safe and reliable means of performing many challenging tasks.