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ABSTRACT

Industrial robots and other robotic systems have been successfully applied at the Savannah River nuclear site. These applications, new robotic systems presently under development, general techniques for the employment of robots in nuclear facilities, and future systems are discussed.

* The information contained in this article was developed during the course of work under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

INTRODUCTION

Nuclear workcells offer obvious requirements for remote handling technology. Radiation, hazardous chemicals, and nuclear contamination in many process areas makes human access either impossible or restricted to short durations with personnel wearing protective gear. Forms of remote handling equipment have been used for many years to assist operating personnel in nuclear process areas. Mechanical master/slave manipulators are employed extensively in shielded "hot" cells for sample preparation, metallography, and nuclear products manufacturing. Similarly, switchbox-controlled manipulators, reactor refueling machines, nuclear disassembly equipment, and remote material handling devices are used for dedicated tasks in reactor, fabrication, and process areas. Despite the use of these devices, operating personnel are frequently required for process monitoring, health physics work, production tasks, and maintenance.

Today, the increased awareness of the potential effects of some chemicals on operating personnel and the use of the ALARA principle for radiation exposure to operating personnel is accelerating the use of modern technologies in nuclear applications. Many process control and monitoring operations are being enhanced with computer controls and sensor technology. Flexible manufacturing and robotics are being applied to nuclear production areas. Mobile remote vehicles and teleoperated arms are being developed to perform repair and cleanup operations. The correct implementation of these technologies is improving safety and reducing costs in a variety of nuclear processes. This paper reviews the development and installation of a variety of teleoperator and robotic systems at the Savannah River nuclear site.

GENERAL

The Savannah River Plant (SRP), which is operated by E. I. du Pont de Nemours and Company for the U.S. Department of Energy, is a complex of separate plants that contain the processes for manufacturing reactor fuel and target assemblies, reactor irradiations, chemical separations of isotopes, and laboratory analysis of products. The site also contains the Savannah River Laboratory (SRL) which operates R&D programs to support SRP production.

Currently, a variety of projects are underway to enhance the plant's older process areas (some of which have operated over 30 years) with automation and state-of-the-art remote handling equipment. The SRL Robotics Group has become very active in the selection, development, and installation of robotic systems for these projects. The major application areas for robotics at SRP include the following:

- Automation of production lines which fabricate reactor components such as fuel and target assemblies. Similar automation applications are being studied for production operations in the reactor areas which assemble and store the reactor assemblies before irradiation.

- Automation of laboratory analyses and shielded cell operations. These applications include taking chemical samples from process lines, performing chemical analyses, and automating handling operations with hazardous process and waste materials.

- Teleoperator development and remote surveillance and maintenance. Several process areas require remote-controlled arms and vehicles to handle nonroutine operations in inaccessible areas.

Robotic equipment has been developed and successfully installed in selected processes in each of these application areas at the site.

MANUFACTURING AUTOMATION

Industrial robots are being integrated into manufacturing areas to handle difficult and unpleasant jobs such as handling heavy uranium slugs, lubricating extrusion dies, and performing material transfers between production machines. These installations improve process safety by removing operators from labor intensive tasks, high temperature areas, and radiation zones. Nuclear production area automation shares many similarities with standard industrial robot applications. The systems must be highly reliable to maintain production rates. FMS (Flexible Manufacturing System) technology, including hierarchical control computers and MAP (Manufacturing Automation Protocol) compatible components, is being used. Current applications are discussed below:

Extrusion Press Lubrication (Figure 1)

An automated system, employing an industrial Unimation 2371 robot, was developed and installed in January, 1985 to lubricate a large extrusion press in the reactor fuel manufacturing area. Special tooling and an improved stirring/mixing operation for the lubricant were incorporated in the system. Recent design improvements have corrected some maintenance and operational problems that were experienced. The overall system is now operating satisfactorily.

Hot Die Sizing Press Lubrication (Figure 2)

A robotic lubrication system employing an industrial Cincinnati-Milacron T3/726 electric robot was installed at a

process hot-die sizing press in January, 1986. A McDonnell-Douglas Robotics Simulation System was used for initial design work and for selection of the robot.

Turret Replacement (Figure 3)

A robotic system to replace a fixed-automation turret, using a Cincinnati-Milacron T3/363 robot, is under development. The turret is used to transfer target assembly slugs in a four-station work cell. The development work involves improved slug handling techniques using a six-axis force sensor (special JR3, Inc.). This system is scheduled to be installed in the process later this year.

Reactor Component Handling

A task committee, consisting of technical, operations, and health protection personnel, is designing a conceptual plan for reactor process automation. Potential applications have been identified and are under study, including automated reactor element assembly and accountability, automated tube storage, and remote disassembly machines. Programs are also being reviewed to enhance fuel charge and discharge operations, tank-top inspections (Figure 4), and emergency response.

LABORATORY AND SHIELDED CELL AUTOMATION

Laboratory analysis and sample preparation of nuclear products are usually either performed in shielded radiation work cells with master/slave manipulators or in gloveboxes. The automation of these processes and the design of support equipment to transfer material to and from analysis areas presents many challenges. Fully automated systems are not generally desirable since work tasks may change or require human intervention and decision making. Several systems have been installed using menu-based supervisory controls which can supply visual, force, and equipment diagnostic information. Controls to allow operators to sequence steps and override programmed tasks have also been developed. Reliability and maintainability are the governing design constraints in these system.

Dilution Vial Filling (Figure 5)

An automated system to fill dilution and reagent vials was designed, developed, and installed in January, 1984. A commerical Zymate Laboratory Automation System, a special vial-capping machine, and special process interfaces were used. The system has operated satisfactorily, except for a short downtime due to an electronic failure in the robotic arm controls, and a laboratory air-conditioning problem (excessive moisture in the environment).

Glovebox Waste Removal (Figure 6)

An automated robotic system was designed and developed to bag-out radioactive waste containers from the SRL Californium Processing Facility. The system employs an industrial GCA 300V five-axis robot, a specially designed end-effector, glovebox access port, and automatic bag-gathering and sealing machine to replace manual operation. It is operated from outside the radiation zone work area via remote controls and TV monitors. The system has operated satisfactorily, with only a few minor problems in the clipping machine. Since its operation began in January, 1985, a personnel radiation exposure dose savings of approximately 35 rem has been realized.

Tracked Robot for Shielded Cells (Figure 7)

An automated system, using a commercial GCA 600V robot on an ESAB track, is being developed to transfer materials into shielded work cells. The system will use an IBM PC to integrate robot control, force sensing, and radiation detection. Benefits from this application include reduced personnel radiation exposure, elimination of personnel contamination potential, and reduced operating costs. Currently, operators require "full-dress" protective clothing for this manual operation.

Sample Aisle Robot (Figure 8)

A special gantry robot was designed, developed, and installed in January, 1985 in the SRP Separations Area to enhance the existing manual sampling procedures, and to reduce personnel radiation exposure. The robot has a three-axis arm driven by DC servo motors from Rockwell AIM-65 control system. It travels on existing overhead I-beams in the sample aisle. Operation has been very successful, with the exception of a failed robot bearing that has been corrected. Recent design changes improved overall performance.

Improved Sample Aisle Robot (Figure 9)

A new, more sophisticated robot is being designed to enhance process sampling operations. This system will have two arms (one, four-axis, heavy-duty; the other, six-axis) and additional robot tasks will be incorporated. An RF control system, a microwave TV system, and a hand-changing system with a rack of special tools will be included.

TELEOPERATOR DEVELOPMENT AND REMOTE SURVEILLANCE/MAINTENANCE

Teleoperator systems refer to remotely-controlled vehicles and arms which operate in environments hostile to humans. The word "operator" in teleoperator reflects the dependence on humans for control of these systems. Some of the early teleoperators which are still being manufactured are the PaR (now GCA Corporation) switchbox-controlled manipulators. Many new teleoperated arms and vehicles are now being sold commercially. It is usually up to the user, however, to integrate the proper tooling and sensors to perform a particular task in a facility. Computers are significantly improving the controllability of modern teleoperated equipment. Multiple link arms can be controlled manually through computer algorithms to move in smooth, straight lines for drilling and cutting operations. Remote vehicles can automatically check sensors, and signal operators to difficulties. Teleoperators which integrate robotic control functions for preprogrammed work are referred to as "telerobots". Advances are also being made in remote maintainability with modular design concepts and remote control communication schemes. Several programs are underway in these areas at SRL.

Pedsco Mobile Robot (Figure 10)

A standard, six-wheeled, Pedsco remote mobile vehicle has been modified with waterproofing shrouds and a microwave TV system (1.84 GHz). This vehicle was successfully demonstrated during simulated emergency conditions in a reactor process room. A new RF controlled vehicle was recently delivered by Pedsco, Ltd. Development of a more versatile manipulator arm and control system is underway.

Another Pedsco remote vehicle is being employed for decontamination operations (Figure 11). Also, a Pedsco vehicle was employed for radiation monitoring after a process leak problem (Figure 12).

WASP Mobile Vehicle (Figure 13)

A four-wheeled, WASP remote mobile vehicle has been puchased from 21st Century Robotics, Atlanta, GA. It was modified to be operated with an electric motor (standard model uses a gasoline engine) and is being evaluated for potential use in several applications. This is a versatile vehicle with a six-degree of freedom, telescoping arm that is eight-feet long and can lift up to 240 pounds. Future enhancements include a hybrid fiber-optic/power umbilical cable and tool-changing capability.

Modular Manipulator (Figure 14)

A modular manipulator arm was built to SRL specifications by Teleoperator Systems, Inc. An in-house development program will upgrade this arm for telerobotic operation. The arm has a 52-inch reach capability and a lifting capactiy of 50 pounds. The manipulator, including its base, is easily disassembled into seven subassemblies to allow it to be remotely maintained. The arm uses motors powered by 24 VDC servo amplifiers enabling its employment on mobile vehicles.

Odetics Walking Robot (Figure 15)

SRL has a contract with Odetics, Inc. to develop, fabricate, demonstrate, and deliver a walking telerobot, ROBIN (Robotic Insect), in March, 1986. It is not being built to withstand an extreme radioactive environment but will be used in a laboratory environment to develop and demonstrate techniques, procedures, and applications for mobile robots. Applications include emergency response operations, routine maintenance, radiation surveillance, decontamination, and removal tasks. It will also be used in a Research and Development program to develop expert robot systems. This walking telerobot will be an improved version of the original Odex prototype, with a telescoping manipulator arm, a tension-controlled fiber-optic umbilical cable, an on-board data acquisition system, and three TV cameras. It will be teleoperated with joysticks and will have an external computer communications interface for programmed robotic operation.

Telerobotic System (Figure 16)

A large telerobot system will be employed in a new facility in SRP to decomtaminate and dismantle obsolete nuclear equipment (gloveboxes, etc.). A five-axis manipulator integrated with a three-axis gantry robot will serve a 70 ft x 20 ft x 20 ft work area. The telerobot system, being manufactured by GCA Corp., to SRL specifications, will handle up to 300 pounds at its end-effector. Operators will control the manipulator with joysticks, function switches, and a computer terminal. Programmed robotic operations will include the tasks of tool changing and other routine operations. System controls will coordinate motions of all axes allowing movement in straight-line trajectories (for cutting and drilling operations, for example).

FUTURE SYSTEMS FOR NUCLEAR FACILITIES

Intelligent Robots and Expert Systems

Most of the applications discussed above employed standard robotic components combined with special peripherals. In some cases special designs and sensory systems were used. These applications, and most applications in industry today, use unintelligent, programmed automation systems. Even the most sophisticated robot systems available are basically unintelligent.

The obvious solution to many problems in nuclear plants and other industrial plants is the effective employment of intelligent robots. Intelligent robots are in their infancy and are not an off-the-shelf item available to industry. Even the most sophisticated of the intelligent robots are still quite limited. Having sight, voice, hearing, and a sense of feel does not make a machine intelligent. Cognitive reasoning ability and sophisticated sensors must be present. Research programs are under way at major universities and research centers throughout the world, and many experimental, intelligent prototype machines are being developed and tested at those institutions.

Even when intelligent robots appear in the industrial market, they will be designed and dedicated to specific tasks. Experimental and development work will be required for the particular plant and application process to develop knowledge bases and expert systems. It will be many years in the future before a generic robot with enough intelligence to perform any job in a plant is practical, or even desirable. A more desirable solution is to have a hierarchical system that contains a large intelligence data base made up of expert knowledge modules. That system will be capable of recognizing a process problem, taking direct action through a standard process control network, then making the decision whether or not to call on a robot. A network of generic mobile robots or multipurpose modular arms would be on standby at robot work stations located at strategic places in the plant. Each work station would contain tools and special equipment that the robot may need to perform many different jobs in its area. When the robot is called on to work, instructions and knowledge about the cause, location, previous history, and possible fixes would be transmitted from an expert knowledge module. The robot would be instantly trained as an expert to perform the task. It would collect the correct tools, proceed to the location, and do the work in constant communication with the supervisor (the program in the main computer). It would acquire additional information at the job site through its own sensory system and knowledge base. Relating this to the human world, it is like having your best, most highly trained person on each task standing by to do the job on demand. The generic robots could be interchanged between jobs and areas without any effect on job performance.

A Research and Development program is under way to develop and demonstrate expert robot systems incorporating expert diagnostic systems, intelligent robots, artificial intelligence, and a hierarchical computer network.

Telerobots

Future applications in the nuclear environment will make more use of telerobotics. Many applications require, and desire, the "human in the loop". The physical interactions from the human can be kept to a minimum using programmed robotics. When practical and desirable, the cognitive reasoning and intelligence of the human can be replaced with proven expert systems. R&D programs at SRL will develop applications using this technology.

CONCLUSIONS

The employment of robots in nuclear facilities is desirable to reduce personnel radiation exposure, enhance safety, and reduce operating costs. At the Savannah River site it has been demonstrated that industrial robots and special peripherals can be effectively applied to nuclear process applications. However, the uniqueness of nuclear applications requires development work to integrate standard components into useful systems. In some applications special designs are required. For facilities not having in-house engineering development capabilities, qualified consultants and "system houses" are available for contract work.

Future systems at nuclear facilities will employ telerobots, intelligent robots, and expert systems.

REFERENCES

1. J. S. Byrd and J. J. Fisher, "The Future of Robotics in Nuclear Plants and Processes", ANS Executive Conference on Remote Operations and Robotics in the Nuclear Industry, Callaway Gardens, GA, April 21-24, 1985.

2. J. S. Byrd, "Mobile Teleoperator Research at Savannah River Laboratory, DOE Workshop on Requirements of Mobile Teleoperators for Radiological Emergency Response and Recovery, Dallas, TX, June 24-25, 1985.

3. J. J. Fisher, "Applying Robots in Nuclear Applications", Robot-9 Conference and Exposition, Detroit, MI, June 1985.

4. J. S. Byrd, "A Site Overview of Robotics and Automation", Robotics and Automation Workshop, Los Alamos, NM, November 1985.

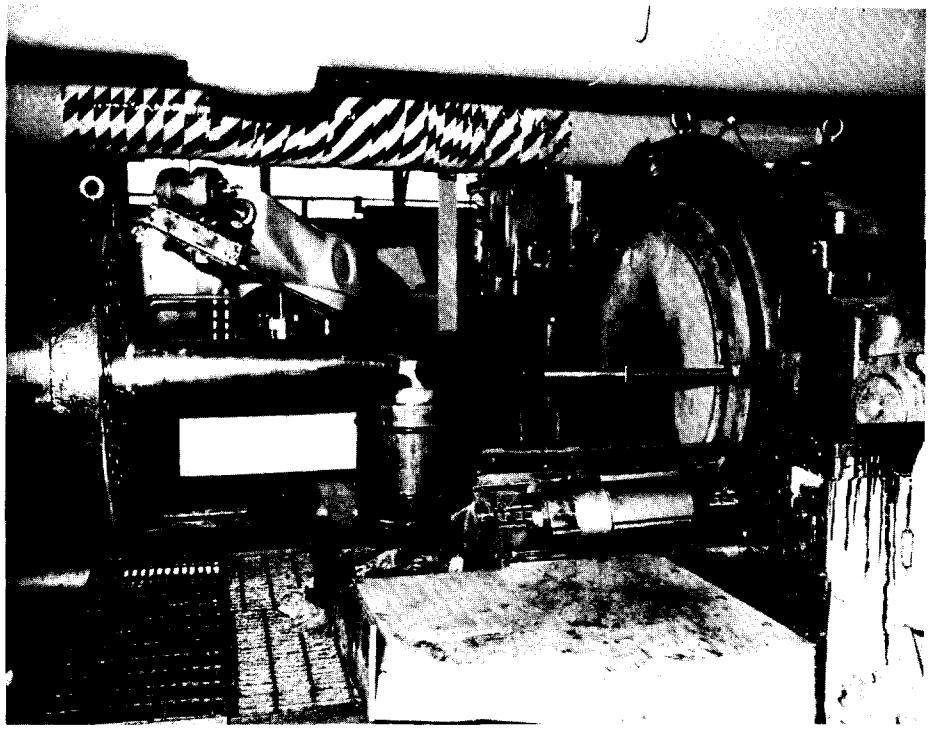

FIGURE 1. Extrusion Press Lubrication Robot

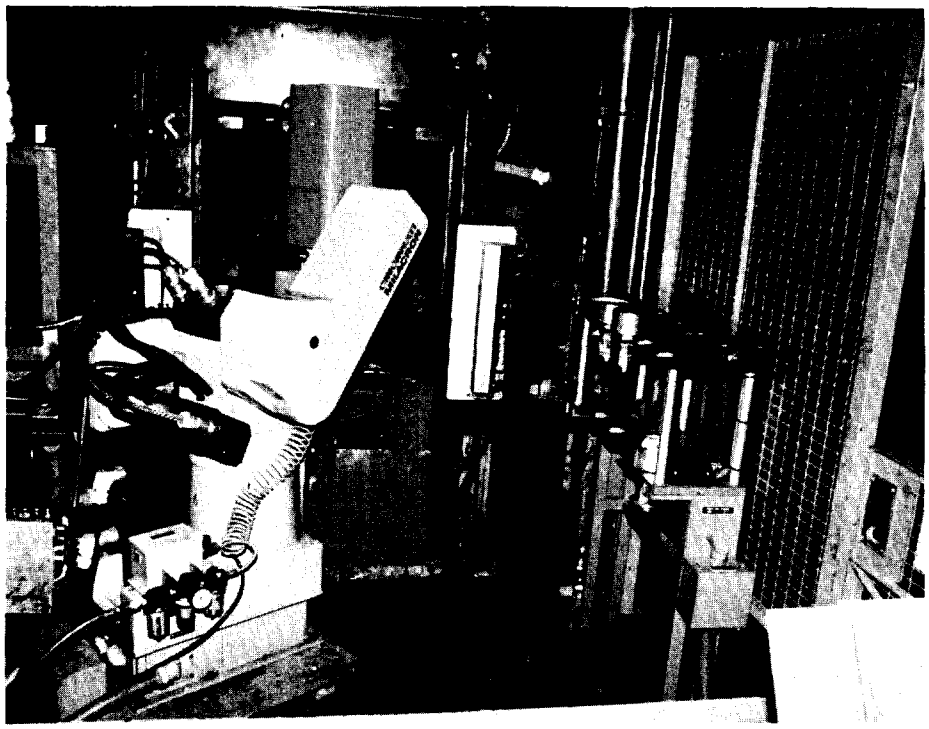

FIGURE 2. Sizing Press Lubrication Robot

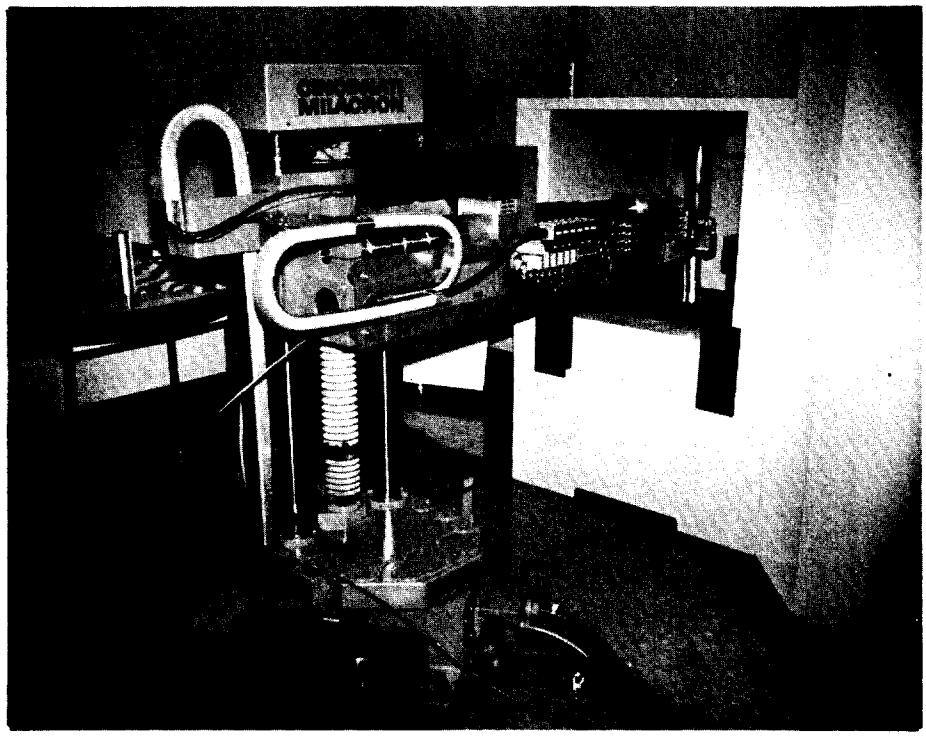

FIGURE 3. Turret Robot Workcell

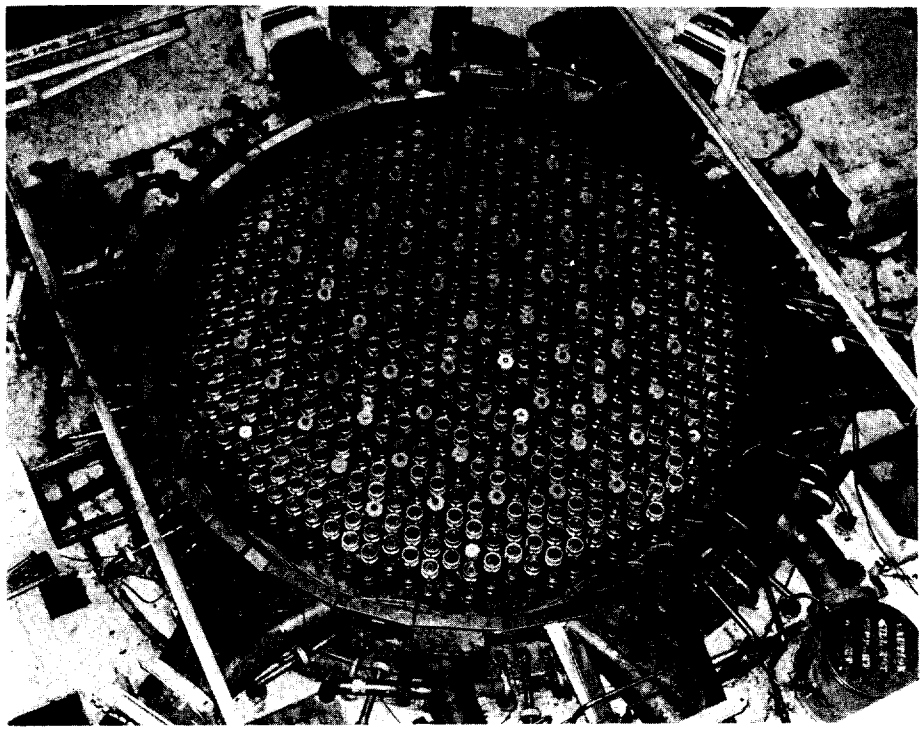

FIGURE 4. Reactor Tank Top

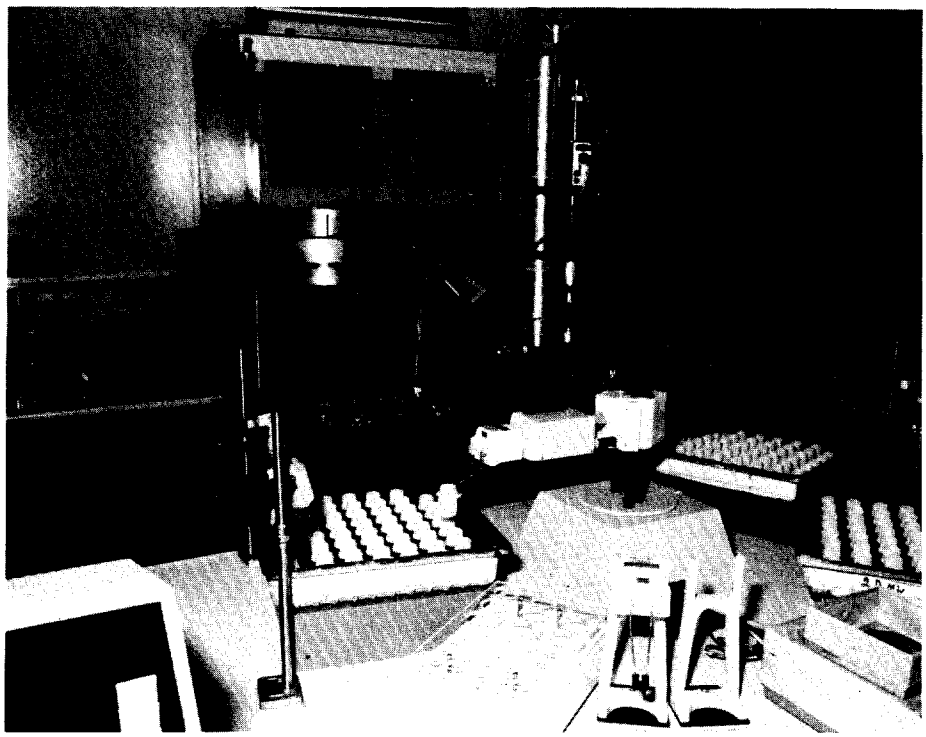

FIGURE 5. Laboratory Robot Filling Vials

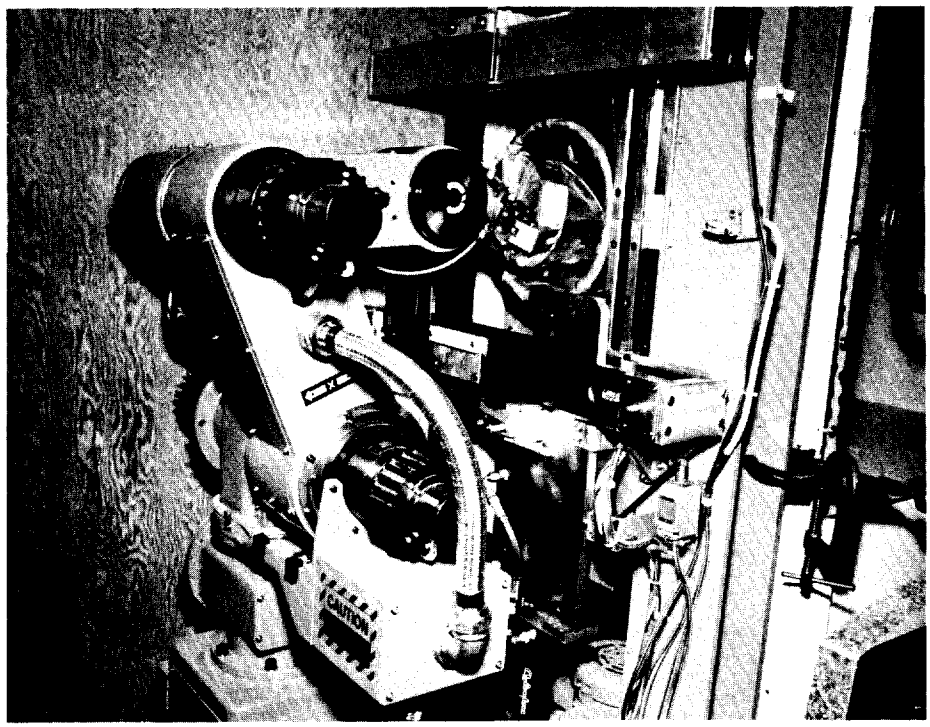

FIGURE 6. Waste Removal Robot

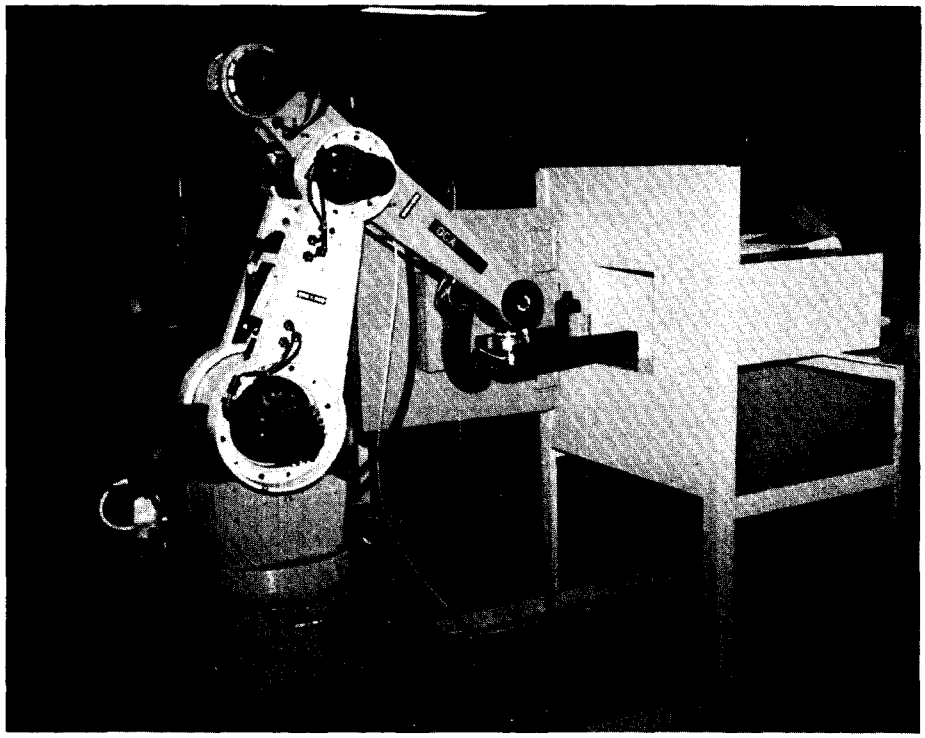

FIGURE 7. Tracked Robot for Shielded Cells

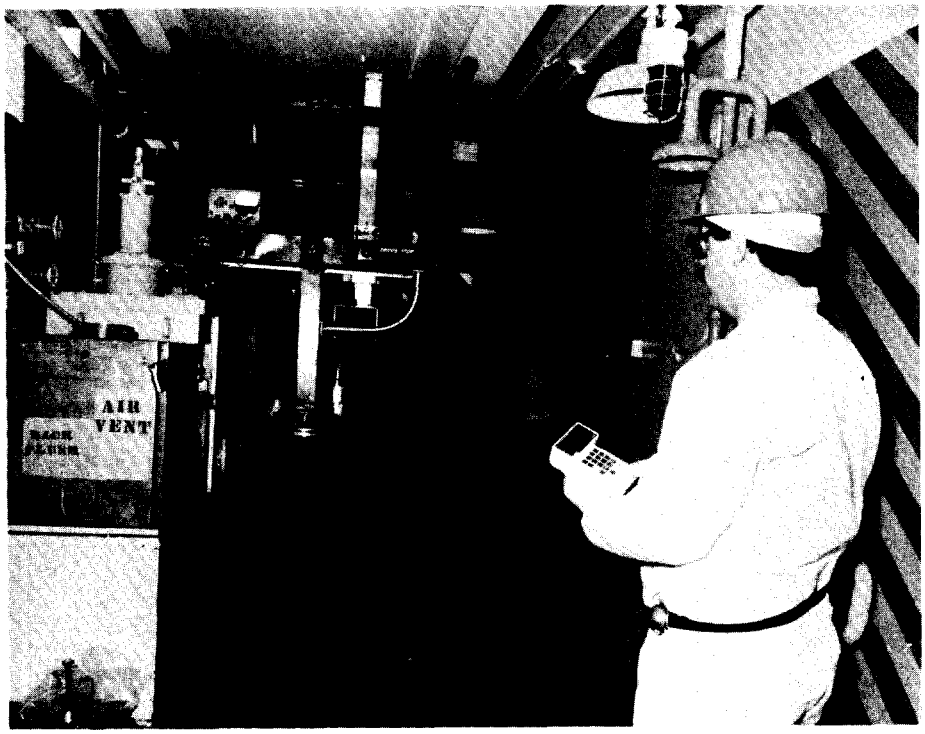

FIGURE 8. Sample Aisle Robot

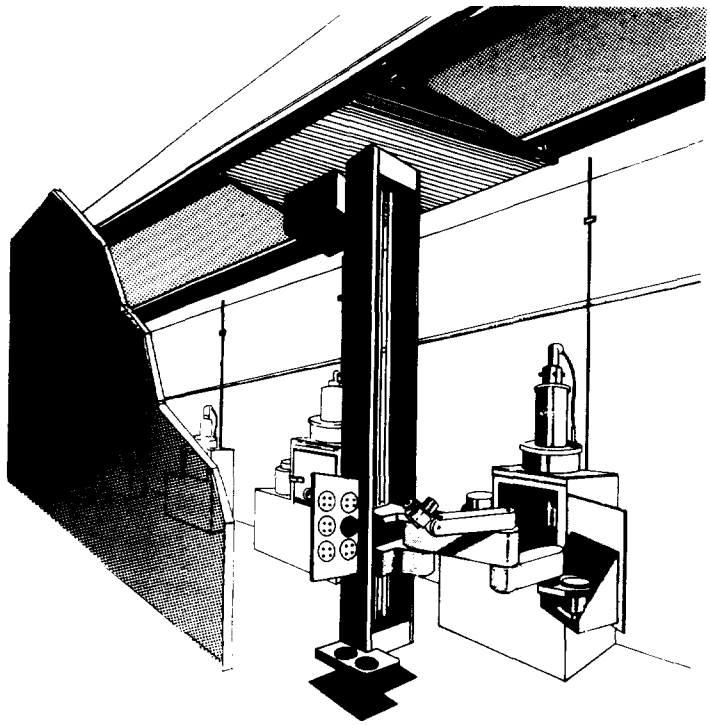

FIGURE 9. New Sample Aisle Robot

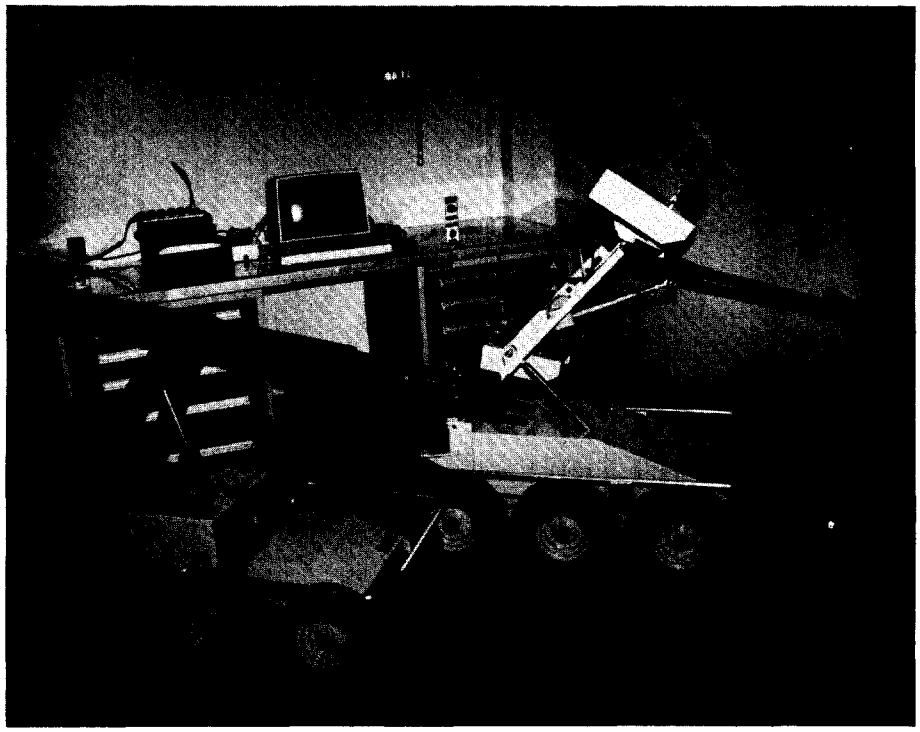

FIGURE 10. PEDSCO Mobile Vehicles

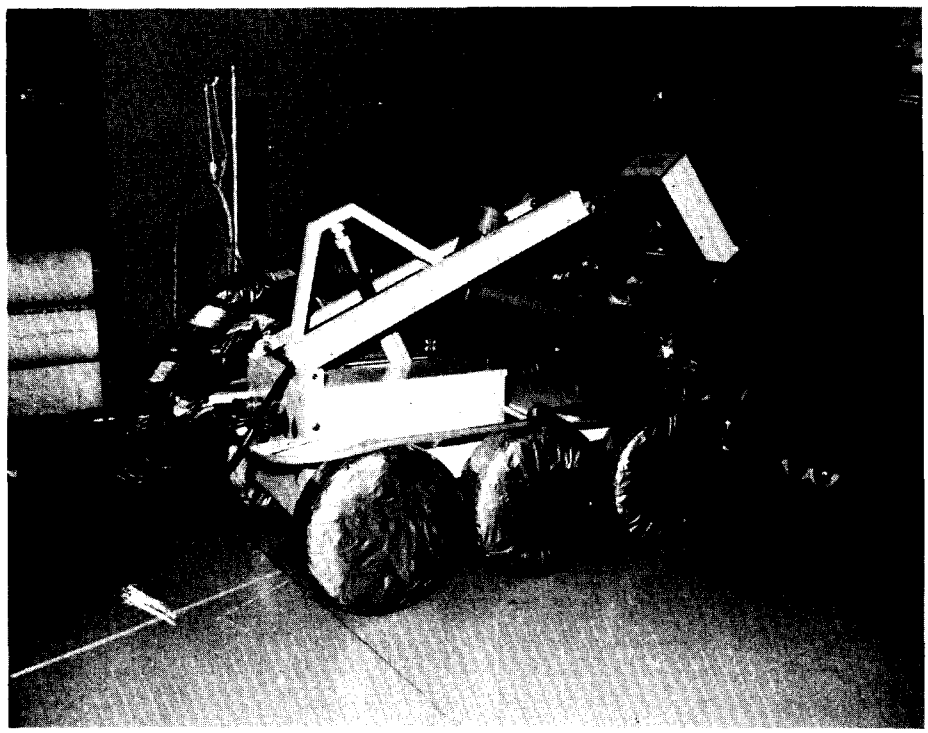

FIGURE 11. Decontamination Robot (PEDSCO)

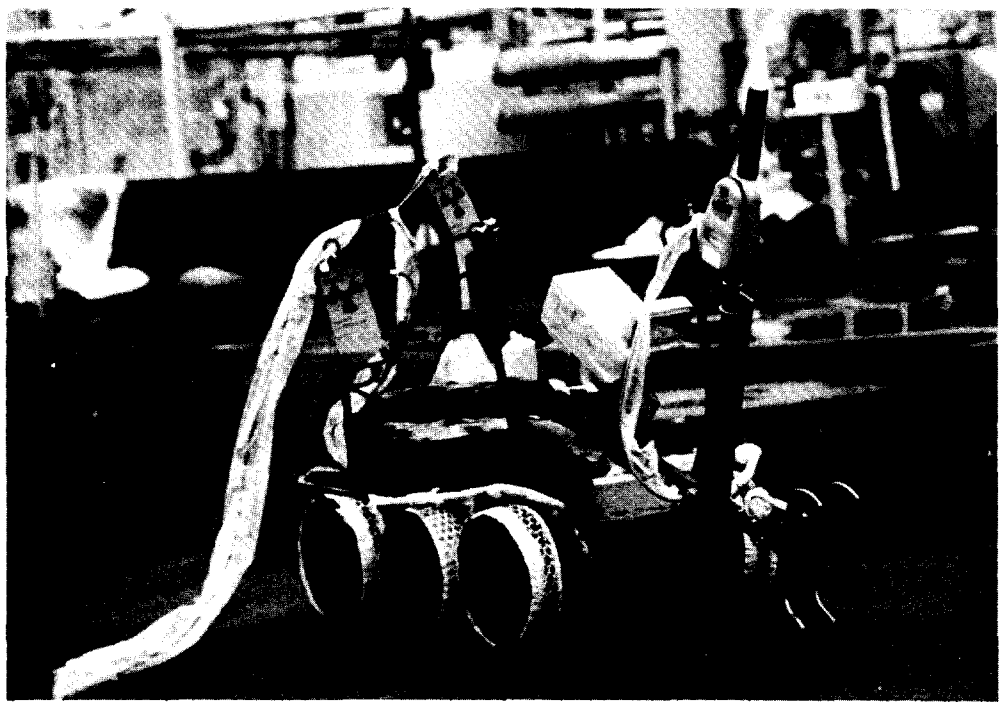

FIGURE 12. Radiation Monitor Robot

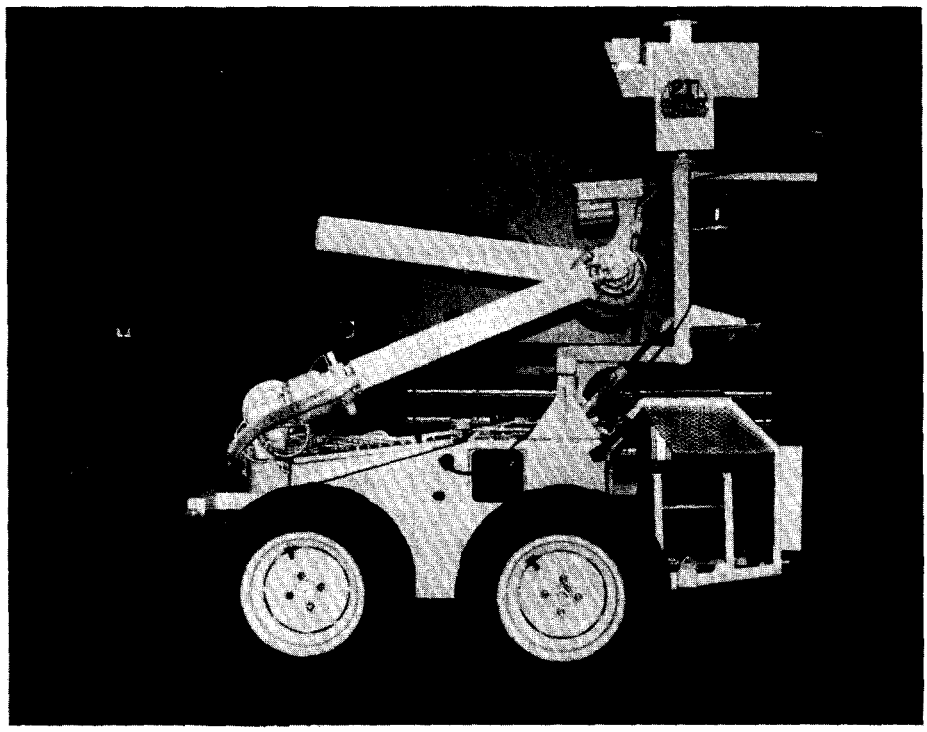

FIGURE 13. WASP Mobile Vehicle

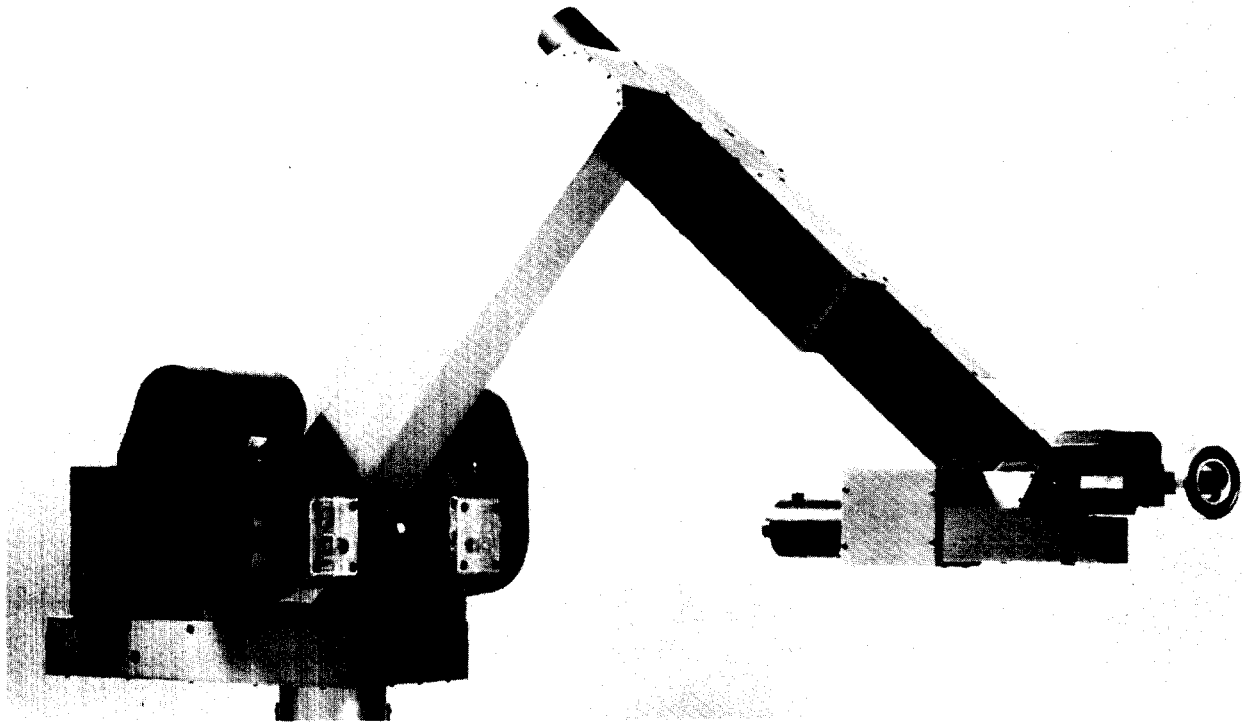

FIGURE 14. Modular Teleoperator Arm

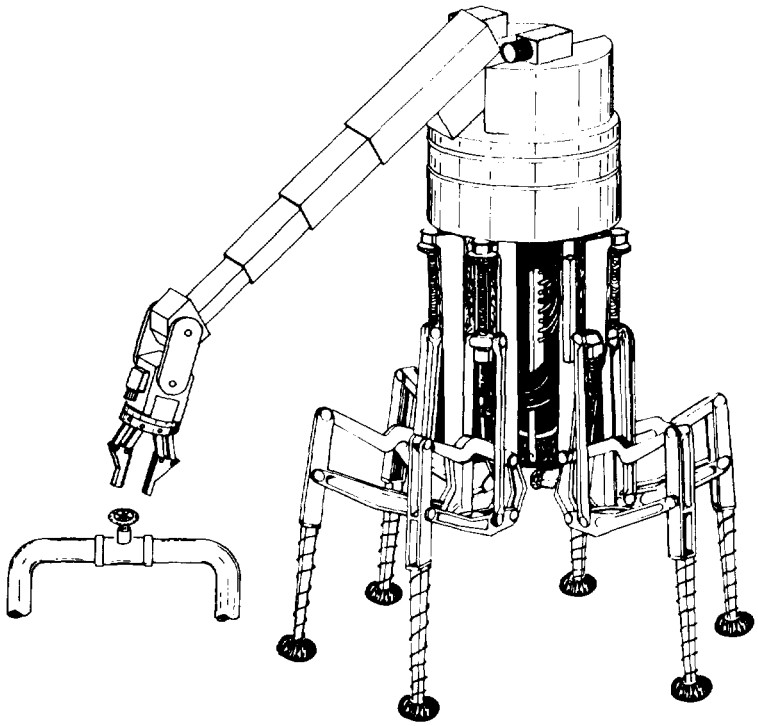

FIGURE 15. ODETICS Walking Robot

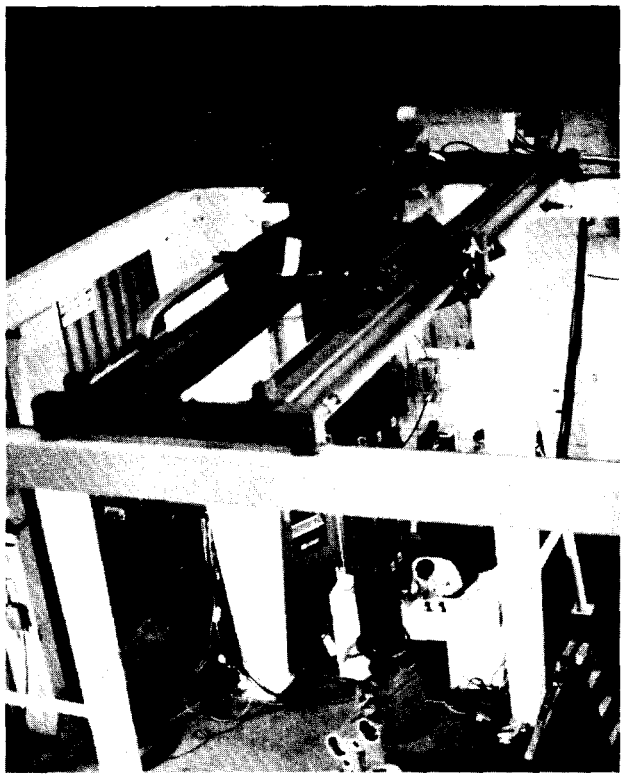

FIGURE 16. Gantry Telerobot