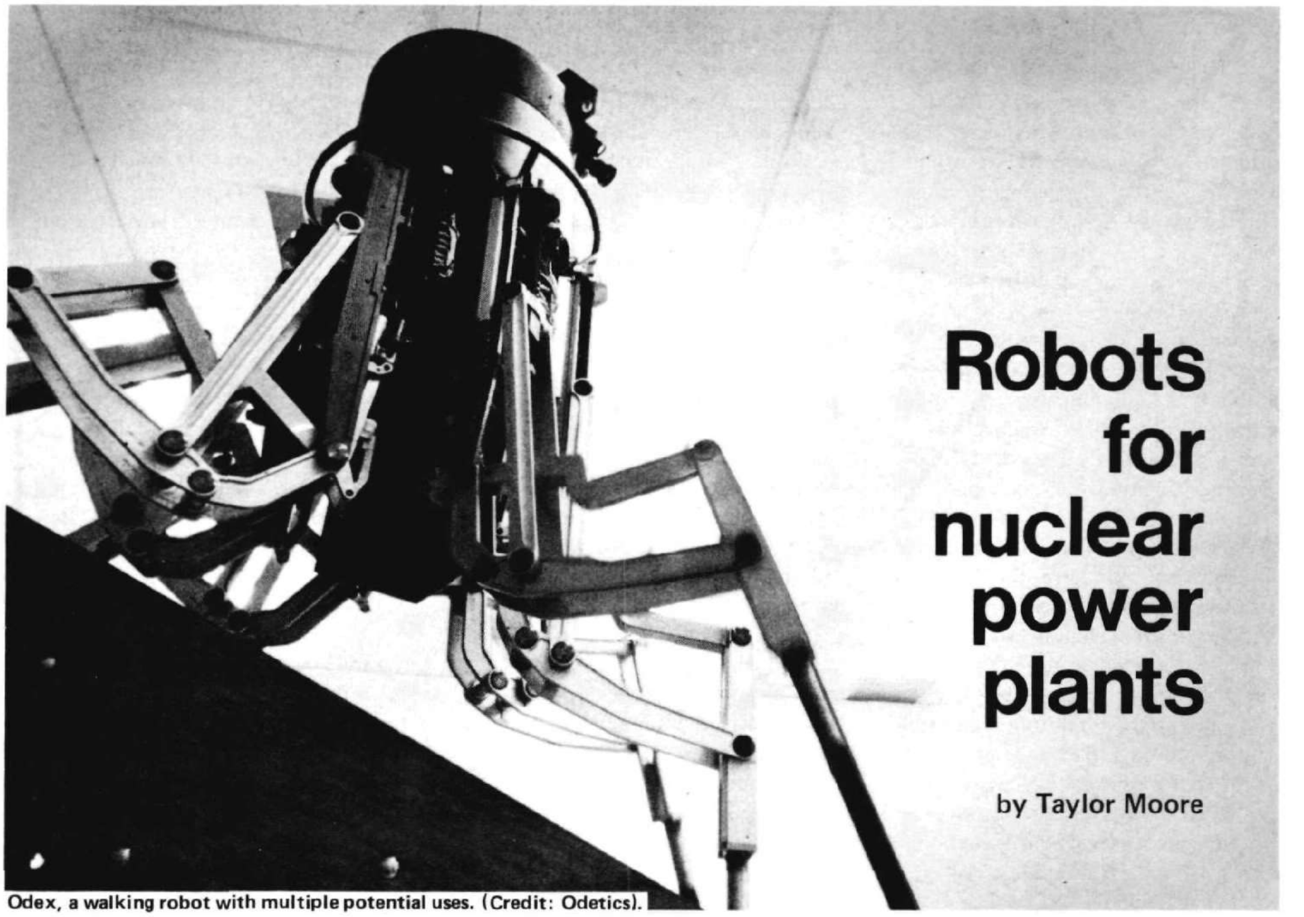
Robots for nuclear power plants

by Taylor Moore



Odex, a walking robot with multiple potential uses. (Credit: Odetics).

In the USA, robotics technology used at the TMI-2 cleanup and at other nuclear plants has prompted interest and shaped research on how robots might best be used

Once confined to the pages of science fiction, robots have dramatically captured the attention of the public and the industrial business community in recent years. Many observers view robots as a hallmark of neoindustrialization, breathing renewed economic vigor and competitiveness into depressed industries through improved productivity and reduced labor costs.

At the same time, however, workers often respond with apprehension to the mental image of a robot performing a task that formerly required a human. The social implications of the robotization of American industry will surely become of more concern to workers, managers, and policymakers alike as more robots enter the industrial workplace.

According to the Robotics Industries Association, only 6300 robots had been delivered in the United States by the end of 1983; most of those had been installed since 1976. But the force of technologic change and the pressure of international economic competition promise an accelerated pace of robot deployment in the years ahead. Some experts predict that as many as 100 000 robots may be at work in this country by 1990—one-tenth of the total number projected worldwide.

For most industries in which robots have been or are expected to be applied in significant numbers, such as automobile production, metalworking, and machinery manufacture, the incentives to robotize relate directly to preserving or recapturing competitive advantage through lowered unit costs of production and improved product quality. But for some industries, the attraction of robots is their potential to work in hazardous environments, thereby reducing the human risks associated with the work.

The electric utility industry is one such industry. Although utilities are not viewed by most industrial robot manufacturers as a significant potential market, special-application robots are under development for performing inspection and maintenance tasks inside nuclear power plants, where radiation levels, heat, and humidity either rule out the presence of human workers or severely limit their ability to work. For many of these tasks in a nuclear plant, robots would be a welcome addition to the workforce, freeing humans from some of the more onerous and discomforting jobs and, possibly, permitting certain tasks to be performed while a plant remains on-line, thus avoiding costly plant downtime for inspection or maintenance.

Some of the robots under development for utility applications represent the state of the art of robotics engineering, and the related research efforts could pioneer advances that have broad application to other industries. EPRI

Mr Moore is on the staff of the *EPRI Journal*, from which this article is reprinted. EPRI is the Electric Power Research Institute in the USA, P.O. Box 10412, Palo Alto, California 94303. EPRI technical contributors to the article were Floyd Gelhaus, Michael Kolar, Thomas Law, Adrian Roberts, and R.K. Winkleblack.

has several current projects aimed at evaluating the technical and economic potential for robot applications in utility operations and at translating the understanding gained from these efforts to the utility professionals who have work aplenty waiting for robots that prove reliable and cost-effective.

Such research is necessarily long range. The robotics industry, fewer than 20 years old by the broadest definition, remains in its infancy, awaiting substantial technical advances in vision systems, miniaturization, and computer controls before truly economic, versatile, and powerful robots are commonplace items of commerce. But R&D success with robots in recent years suggests that such machines will emerge from the laboratories and enter the commercial market before this decade is over. EPRI's research in robotic applications, at least in part, is intended to ensure that when that day arrives, utilities will have a clear understanding of the work robots can do for them and whether it makes economic sense to put them to work.

Robots for nuclear plants

The use of remotely operated and robotlike equipment to protect nuclear workers in high-radiation areas is not new. John Taylor, an EPRI vice president and director of the Nuclear Power Division, divides robotic equipment in nuclear applications into two broad categories: single-purpose devices with limited ability to perform different operations, and reprogrammable, multipurpose robots with some degree of computer-based artificial intelligence.

"I think the first category has reached a reasonable level of maturity," says Taylor At EPRI's Nondestructive Evaluation (NDE) Center and among reactor manufacturers, nuclear service contractors, and some utilities, these types of devices are in use today for such tasks as pipe cutting, welding, steam generator tube inspection and repair, and ultrasonic scanning of pipe sections for crack detection. "These devices have proved to be absolutely essential; we simply could not get some jobs done without them," adds Taylor.

Robots in the second category, those with sufficient computer-based intelligence to support a variety of applications, "have a long way to go," in Taylor's words, before they can demonstrate significant practical benefit in nuclear plant operations. But, as Taylor adds, such robots are under development, and their initial trials are expected to provide valuable insight to their ultimate potential.

Soon after remote manipulator arms were developed for use in hot cells and fuel reprocessing activities, an arm mounted on a transporter with cameras and lights made its debut in the 1950s at the government's Hanford nuclear facility in Washington State. Developed by Westinghouse Hanford Co., the remotely controlled transporter vehicle was dubbed Louie after a technician scrawled the nickname on the robot's arm. Louie has proved to be a versatile and long-lived workhorse and is still in use today.

Some fundamental aspects of how this equipment is applied distinguish robotic equipment for nuclear plant applications from the more widely familiar industrial robots—those fixed devices that typically are employed for pick-and-place operations or other highly repetitive tasks.

In many industrial applications of robots, the objective is to replace human workers with machines that are more productive, efficient, and accurate. But for nuclear applications, the objective is not so much to replace workers as it is to extend their presence—for example, to project their reach into areas of a nuclear plant where the thermal or radiation environment prohibits or limits a human presence.

"In contrast to most robotic applications, we want to keep man in the loop, rather than replace him, to observe the work, make decisions, and control the robot," according to R. K. Winkleblack, an EPRI project manager in the Nuclear Power Division. "Strictly speaking, the devices we are looking at are remote-controlled equipment, not true robots," adds Winkleblack

Improving availability

The economic motivation to use robots for nuclear plant inspection and maintenance is centered on their potential for improving plant availability; a byproduct is the potential for reducing the occupational radiation exposure (ORE) of plant personnel.

Many inspection and maintenance tasks can only be done when the reactor is shut down because radiation levels under operating conditions would be too high even for humans fully outfitted in protective clothing. These jobs are usually deferred until scheduled refueling outages to minimize plant downtime. They thus can become part of the critical path of activity needed to bring the plant back into service.

Delays are critical to plant availability, as well as costly Purchased replacement power to substitute for the output of a 1000-MWe reactor costs an average of $500 000 a day. Robots potentially could contribute to improved plant availability by avoiding delays in scheduled outages and handling some tasks while the reactor is operating.

Nuclear workers are currently limited by federal regulation to no more than 3 rem per quarter-year or an annual total of 5 rem.* This means that for many routine jobs large numbers of workers must be assigned a small portion of the work because each will quickly reach the ORE limit and must then be restricted to nonradiation areas until the next quarter. Consequently, utilities are forced to employ significant numbers of transient workers, or so-called jumpers—temporary personnel who move on to other jobs after receiving the ORE limit.

According to a Nuclear Regulatory Commission (NRC) estimate, every man-rem of personnel exposure has a value to utilities of $1000, although some utilities assign a value of as much as $5000 a man-rem. Some types of work, such as health physics surveys and inspection of primary reactor cooling systems, can involve radiation fields of several hundred rads an hour.

Utilities may face even tougher ORE limits in the future. In addition to guidelines that call on utilities to reduce OREs to levels "as low as reasonably achievable," NRC for several years has been studying proposals to reduce the ORE standards; such a development could have a multiplicative effect on utility costs for personnel exposure.

Feasibility studied

EPRI and NRC have both sponsored preliminary assessments of the potential for applying robotics in nuclear power plants. NRC, motivated primarily by the objective of reducing personnel radiation doses, looked mainly at surveillance and inspection tasks in a study performed by Remote Technology

* In international usage, the rem has been replaced by the sievert in accordance with recommendations of the International Organization for Standardization. One sievert corresponds to 100 rem.

Corp. EPRI's analysis, conducted by Battelle, Columbus Laboratories, focused on maintenance activities and attempted to identify potential availability improvements, as well as opportunities to reduce radiation exposure.

Each study attempted to quantify the cost in ORE and man-hours of a variety of jobs that a robot system might be capable of performing; the costs were then compared with those of the robot and its associated support systems and personnel

Surveillance and inspection tasks evaluated in the NRC study range from detection of steam or water leaks, verification of valve positions, and reading of gages to measurement of radiation levels in components and various methods of sampling to detect contamination. The EPRI study surveyed 22 tasks that are performed routinely or during refueling, including control rod drive maintenance, steam generator tube repair, and repair or replacement of various pumps and valves.

Although the scope of activities analyzed were different, both studies concluded there were potentially significant net positive economic benefits of applying robots in nuclear plants The NRC study, based on application of a cost-benefit methodology to two existing plants, concluded that commercially available robotic technology can be retrofitted into existing plants and will reduce both radiation exposure to workers and plant operating costs.

The NRC study cautioned, however, that benefits can differ significantly among plants because of dissimilar design factors and operating histories. The report encourages utilities to perform plant-specific cost-benefit analyses, including consideration of all costs of personnel entry into radiation areas, to determine whether robotic applications for such inspections are economical.

In the Battelle study for EPRI, potential maintenance applications were screened to identify candidate tasks common to many nuclear plants that account for a significant share of maintenance costs and are amenable to performance within the limits of current robotic technology. Follow-on cost-benefit analyses were performed for the application of robots to reactor cavity cleaning, health physics surveys, and flange unbolting/rebolting. Despite the amenability of these tasks to current robotic technology, it was concluded that none could be performed robotically without further technology development.

Using the net present value method, Battelle researchers found that robots for reactor cavity cleanup and maintenance bolting activities would pay back in less than one year, while health physics survey applications would pay back in about three years. The results were then tested with a range of values for outage time and radiation exposure costs.

Even with the lowest values ($700 per man-rem exposure and $300 000 a day outage time costs), robotization of maintenance bolting would pay back in slightly more than one year, while health physics survey tasks would require less than four years to pay back, the study found. Overall, the study indicated cost savings ranging from $100 000 to $1 million in net present value per robot, with the purchase price for each robot projected at under $200 000.

An important caveat noted by the Battelle researchers, however, is the limited availability of commercial robotic equipment geared specifically to nuclear applications. Because the nuclear industry has not been a major market for robot manufacturers, the business has generally been left to smaller entrepreneurial firms that can adapt robotic equipment for low-volume applications.

The nuclear industry thus needs some way to fund these developments or to attract entrepreneurs who are willing to financially shelter the technology during its demonstration phase, the study points out. This is in contrast to the situation in Japan, where a cooperative relationship between utilities and vendors has led to a more unified approach

Prototype development

The core of EPRI's research in robotics is its participation in the development and testing of several prototype robot systems that could be forerunners of commercially available machines Some of these robots could be used as transport vehicles to carry other robotic equipment, such as a flange unbolter or a steam generator tube-repair robot, into a high-radiation area, set up the smaller device at work, and then monitor its activity. Some, on the other hand, may be less capable of doing demanding labor, but could be used as intelligent master robots, controlling the work of stronger drones.

Several robot prototypes are making their debut in the recovery and cleanup of the damaged Three Mile Island Unit 2 nuclear plant in Pennsylvania, the site of a March 1979 loss-of-coolant accident that destroyed much of the reactor core and left large areas of the reactor containment building inaccessible to humans. Remote inspection has shown radiation fields as high as 3000 rad/h in some areas of the containment.*

According to Adrian Roberts, a senior program manager in EPRI's Nuclear Power Division and manager of its TMI-2 information and examination program, the TMI cleanup effort has become a particularly strong spur to robotic equipment development. "At TMI we have a challenge for robotics that is here and now, some of the jobs simply can't be done other than remotely. And because we can't wait for the ultimate robot, we're taking advantage of work from a number of areas to develop robots that will get the jobs done. If robots are shown to be feasible for certain jobs at TMI, they can be applied at other nuclear plants."

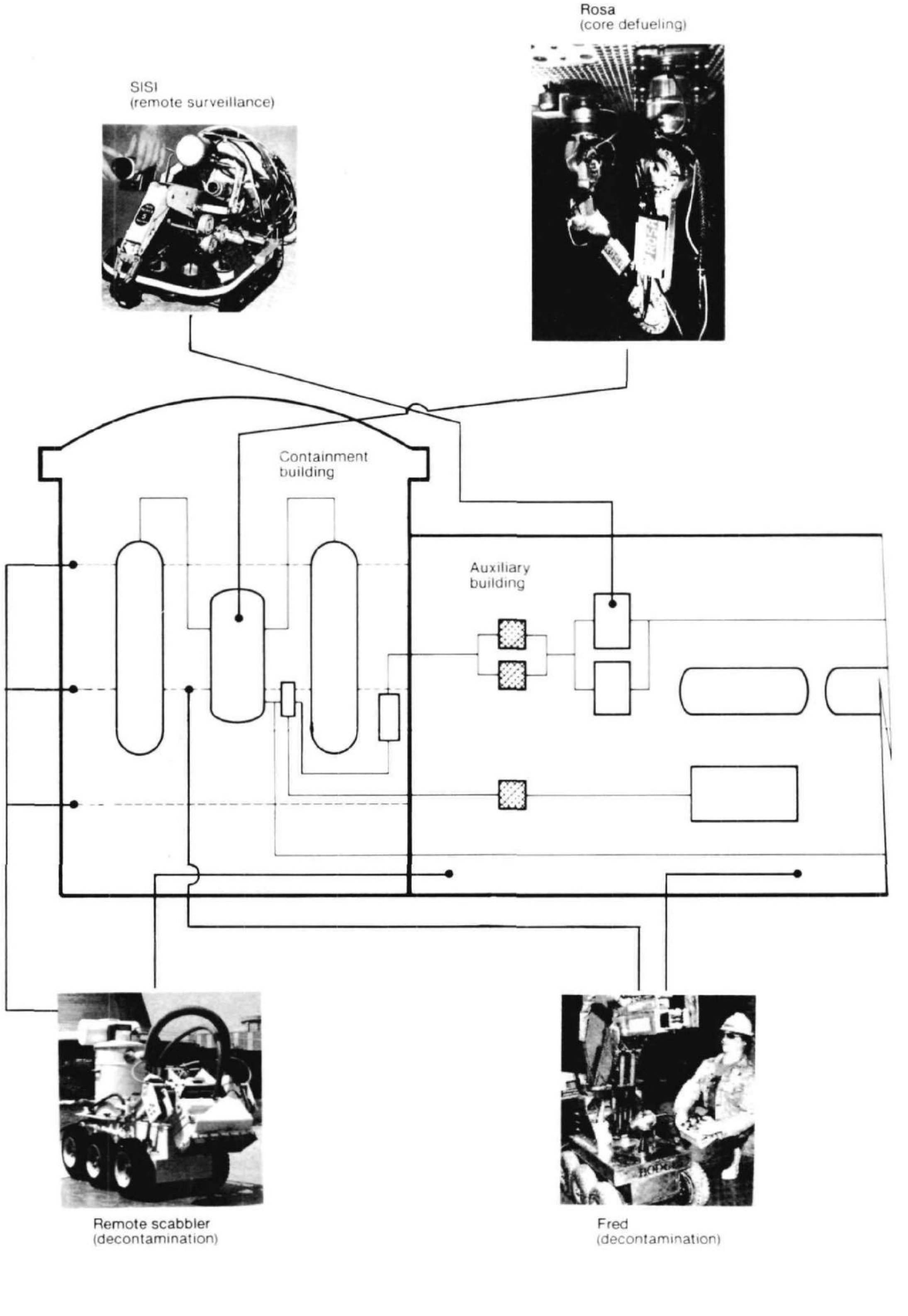
Robots, in fact, have been tried at various times at TMI since the accident. In August 1982, a 25-lb (11-kg), remotely-controlled, tracked, tanklike vehicle supplied by DOE and called SISI (for system in-service inspection) was used to photograph and obtain radiation readings in areas surrounding the plant's water makeup and purification system. The water system's filters are highly contaminated with fission products from the primary core cooling system. The following spring, a six-wheel remotely-controlled device dubbed Fred was outfitted with a high-pressure water spray and used to decontaminate the walls and floor of a pump cubicle in the auxiliary building basement. Fred weighs in at 400 lb (181 kg); its mechanical arm can lift 150 lb (68 kg) and extend to a height of 6 ft (1.8 m).

The venerable Louie from Westinghouse Hanford has been brought to TMI to perform radiologic characterization during decontamination of the water purification system. Officially known as the remotely controlled transporter vehicle, Louie will be used to monitor radiation levels as the demin-

* In international usage, the rad has been replaced by the gray. One gray corresponds to 100 rad.

Robots at TMI-2

Cleanup and recovery work at the damaged TMI-2 reactor in Pennsylvania presents a unique challenge for the application of robotics technology. Two remotely operated manipulators called Fred and SISI have already seen service in surveillance and decontamination tasks. The RRV, nicknamed Rover, has been assigned the job of inspecting the contaminated basement of the reactor containment building. A remote scabbling machine has been developed to remove contaminated layers from concrete floors. Louie, specially modified for the TMI work, is slated to monitor radiation levels as the plant demineralizer tank is decontaminated. Rosa, a versatile remote manipulator arm, has been proposed to lend a hand in defuelling the TMI-2 reactor core.



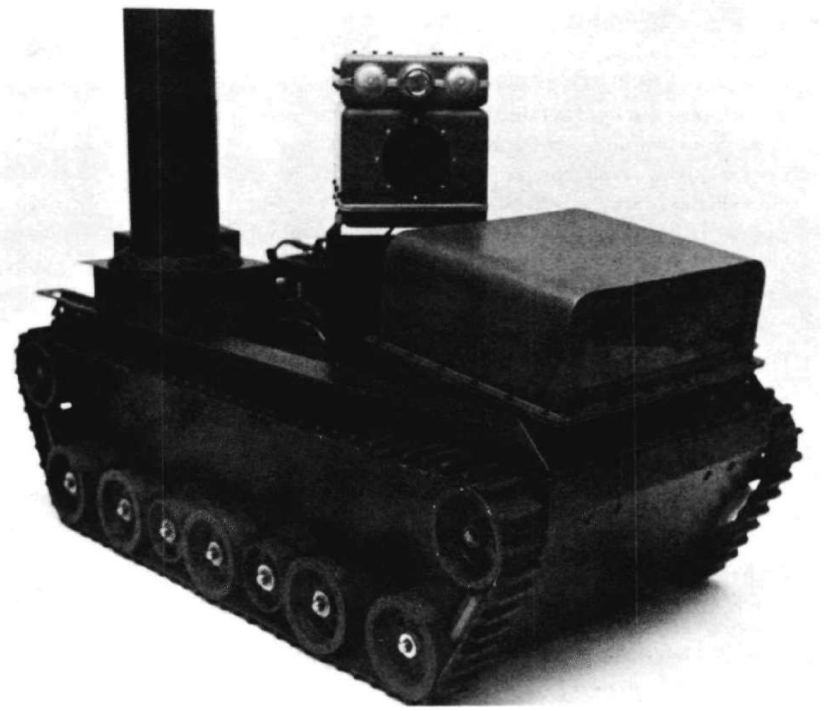
eralizer resins in the water system are flushed out. Though the robot's nearly 1000-lb (454-kg) lifting strength will not be needed in this operation, its radiation-hardened television cameras will get a workout near the demineralizer tank, which has a contact reading of 3000 rad/h.

Perhaps the most ambitious effort to date to apply robotics in the TMI cleanup has been the EPRI-supported development by Carnegie-Mellon University's (CMU's) Civil Engineering and Construction Robotics Laboratory of the remote reconnaissance vehicle (RRV) to probe the basement of the reactor containment building. The basement level, where no human has entered in over five years, remains highly contaminated with the radioactive sludge left from some 600,000 gallons (2270 m^3) of water, including primary cooling water, most of which has since been pumped out.

The RRV, nicknamed Rover by GPU Nuclear Corp., the operating utility at TMI, has been assigned the task of entering the dark and damp basement by crane hoist, inspecting the scene with its three television cameras, and surveying the area radiologically with several on-board detection instruments.

The six-wheel, 1000-lb RRV, developed in a cooperative effort involving EPRI, CMU, GPU Nuclear, DOE, and the Ben Franklin Partnership in Pennsylvania, was designed by CMU's William Whittaker, an assistant professor of civil engineering and director of the robotics laboratory. It features an innovative on-board umbilical reeling system designed to permit the vehicle to negotiate obstacles without dragging the umbilical. A stainless steel frame mounted atop the transporter base carries the umbilical reel, cameras, monitoring instruments, and control systems. The vehicle has also been designed for quick decontamination with water spray after it is removed from work areas.

A two-person crew controls the RRV from a console equipped with television monitors that is located a safe distance away from the hazardous area (at TMI, this distance is over 500 ft, or 150 m); one person steers the craft and manipulates the cameras while the other operates the umbilical reel. Teams of operators practiced maneuvering the RRV for several months along an improvised obstacle course in the adjacent turbine building (the staging area for much of the cleanup work) in preparation for lowering it into the containment basement.



IRIS — for Industrial Remote Inspection system — is a general-purpose robot for hazardous environments. (Credit: EPRI)

The RRV is the first of three similar remote vehicles to be developed under the joint TMI recovery program. An important feature of the design is that the frame mounted on the chassis can be removed and other equipment added to the transporter. The second RRV base vehicle, modified by Pentek, Inc., EPRI's site contractor at TMI, is outfitted with a pneumatically powered scabbling machine and vacuum system for removing the contaminated top layer of concrete from floors in parts of the reactor building.

A third RRV remains at CMU's robotics laboratory for future development efforts. Other tasks proposed for future modifications of the prototype RRV include collection of liquid and sludge samples from the containment basement, collection of concrete core samples from the floor and walls, and some minor structural dismantling.

"At TMI the interest is in working vehicles with high strength, reliability, and mobility," explains Whittaker, the RRV's designer. "The challenges at TMI are very physical and active, and the equipment that will meet those challenges will be similarly physical and active. But there is certainly no one machine that will do it all, so we are looking at the evolution of a family of these things. One mode might be a fully configured RRV to supervise the activity of a drone that would carry tools only. Another possibility is a miniature version of the RRV that would operate radio-remote from the mother ship."

Clearly, robotic equipment is proving to be a valuable tool in the TMI recovery effort. Other applications of robots at the site are also planned. A manipulator arm built by Westinghouse Electric Co. and known as Rosa (for remotely operated service arm) has been proposed for use in the defueling of the TMI reactor core, tentatively planned for next year. Rosa, which can also operate underwater, is already known among some utilities operating pressurized water reactors for its ability to automatically inspect and repair steam generator tubes after it is mounted on the steam generator by service personnel.

Waiting in the wings

In addition to the robots that have been deployed at TMI, EPRI is evaluating two other prototype devices that could prove useful in nuclear plant environments. These machines could become cousins of the TMI machines in the robot family that Whittaker envisions.

One of these, produced by Advanced Resource Development (ARD) Corp., is known as an industrial remote inspection system (IRIS). Designed as a general-purpose surveillance and inspection robot for hazardous environments, IRIS is a relatively small (compared with the RRV) battery-powered, tracked transporter that can be equipped with optical, audio, and environmental sensors; manipulators; and communications and control subsystems.

The 200-lb (91-kg) IRIS features a unique high-frequency wireless communication system, specifically designed to operate in an environment cluttered with physical barriers, as well as with signal interference, which allows it greater mobility and range than most robots developed to date. A telescoping arm and a three-dimensional television system with zoom lens and microphones mounted on a pan-tilt pad bring the current payload to 70 lb (32 kg). Eventually, IRIS will contain some limited on-board intelligence, enabling it to retrace its steps backward even if normal control signals are lost or blocked by interference.

According to Floyd Gelhaus, an EPRI program manager who is evaluating IRIS and other robots for potential nuclear applications, the current ARD device has been designed strictly as a remote surveillance vehicle. "Its ability to do robust tasks is limited," says Gelhaus, "but the mobility and untethered configuration of the transporter, with its ability to carry various payloads, make it a valuable member of a robotics staff."

Gelhaus plans to have technicians at EPRI's NDE Center put IRIS through its paces before taking the robot into a recently constructed, nonradioactive plant environment. Duke Power Co. has agreed to host the testing activities at its new Catawba nuclear unit. The final step will be to test and evaluate the device in an operating plant.

Gelhaus is also considering possible applications for what is probably the most advanced robot developed so far—a six-legged, free-walking machine known as Odex. The Odex prototype, built by Odetics, Inc., "represents a remarkable breakthrough in its strength-to-weight ratio," comments Gelhaus, as it can lift more than five and a half times its 370-lb (168-kg) weight. Almost any other robot can heft little more than one-twentieth of its weight. "With that kind of power, there are a lot of potential applications," adds Gelhaus. Odetics has demonstrated Odex on videotape around the country, including scenes of it lifting the end of a compact pickup truck.

Because each of Odex's articulators, or legs, uses its own microprocessor, with a seventh computer coordinating overall movement, complex maneuvers are possible under the control of either an operator or a remote computer. The machine can pirouette 360° while simultaneously advancing in any direction. Its jointed legs permit it to assume six distinct profiles, ranging from a narrow stance for negotiating tight doors to a low squat. Odex is outfitted with twin TV cameras for visual transmission.

"Odex is a breakthrough in the state of the art," says Gelhaus, "but it will take some careful research to define applications for it in a nuclear plant." EPRI's work with Odetics has led to conceptual design modifications that will enable Odex to negotiate a power plant's internal obstacle course.

Future development

Technologically, Odex may be close to the fully autonomous, intelligent robot that researchers say would represent the ultimate marriage between machine automation and the developing field of artificial intelligence Its ability to maneuver around or over obstacles under the guidance of a remote operator approaches the level of computer control integration that will be needed if a robot is to be capable of autonomously responding to a programmed set of directions by referencing a self-contained data base for its location, destination, route, and tasks.

Consummating the union between robots and artificial intelligence is a long-range research goal, however, because the challenges involve advancing the frontiers of computer modeling of solid geometry, as well as the structuring of large amounts of computer data for logical access by the robot. Various military and nonmilitary research programs around the country are now focusing on the mathematical and computer science aspects that will eventually be brought to bear on this challenge. The military programs are largely funded by the Office of Naval Research and the Defense Advanced Research Projects Agency. Others, including programs at Stanford University, Purdue University, the University of Michigan, the Massachusetts Institute of Technology, and CMU, involve nonmilitary as well as military-related R&D.

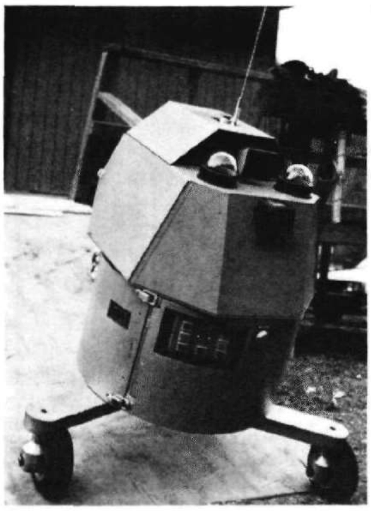
Irving Oppenheim, an associate professor of civil engineering at CMU, is working with EPRI on some aspects of the problem in a research project to assess the potential for applying artificial intelligence in robots for construction and maintenance work. The Japanese already make significant use of automatic devices for various tasks in construction, but, in general, these devices are not the smart type. Two elements that are needed to make robots autonomous, according to Oppenheim, are the ability to logically detect and avoid obstacles and a way of modeling the three-dimensional work environment of the robot so that its "world map" can be referenced as it proceeds on an assigned task.

"There are some attempts at the mathematics that will permit a robot to find a configuration that avoids an obstacle, and we are working with the existing ones, testing them out, finding their shortcomings, and modifying them to accomplish some of the objectives that these obstacle avoidance capabilities are going to have," says Oppenheim. "For example, we're testing whether a control algorithm can figure out how to command a robot to reach around two pipes, then reach in and touch a third pipe."

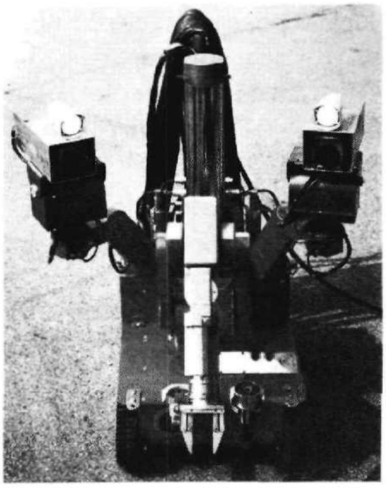
Progress in the second area of research—providing the robot with an accurate, three-dimensional model of its work environment—could someday lead to a robot's direct use of the original and as-built design drawings of an entire nuclear plant Explains Oppenheim. "There must be a data structure, a computer program, that stores all the plant dimensions, the wall openings, solid areas, pipes, intersections, and so on.

"There are two approaches to this problem. One is to build a robot that has sensors all over it and simply keeps it eyes and ears open and doesn't touch anything. The other way is to somehow make use of all the dimensional data that have already been recorded and are on drawings and computer-aided design systems. We are exploring the kind of computer data structure that is best suited to the problem."

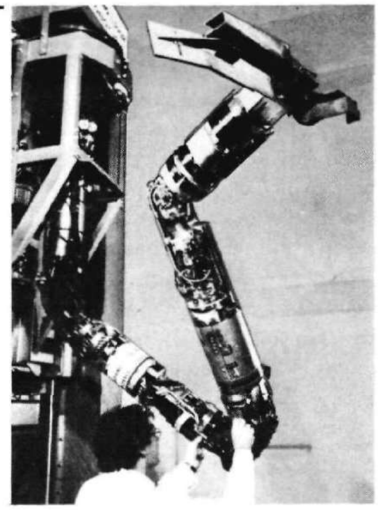
Designing nuclear plants with robots in mind is another area in which EPRI has sponsored research. Many of the difficulties involved in using a robot to-



This radio-controlled robot called "Kluge" was designed for surveillance and to carry different types of equipment. (Credit: Cybernation Inc.)



"Herman" is a mobile manipulator at the Oak Ridge, Tennessee Y-12 plant used as a stand-by system to work in toxic or radioactive environments. (Credit: Martin Marietta Energy Systems, Inc.)



ISIS, developed by Hispano Suiza, is being used at France's Chinon A3 reactor for repairs. (Credit: Hispano Suiza)

Robotic evolution

Although the robotics industry itself is less than two decades old, the technology can broadly claim old and distant relatives — from musical statuettes to mechanical manipulators and programmable machines — around the world.

Early Greeks, Egyptians, Ethiopians, and Chinese, for example, created a variety of moving figures that were powered by water and steam. Later, in the 18th and early 19th centuries, Swiss craftsmen built life-like "automata" that could write, draw, and play musical instruments; and the French developed mechanical looms controlled by punched cards, introducing the first programmable machine.

The term "robot" itself, however, was not widely used until 1921, when the play *Rossum's Universal Robots* opened in London. Written by Czechoslovakian dramatist Karel Čapek, the play popularized the derivative of the Czech *robota,* which means forced labourer.

Today the definition of the word "robot" illustrates both rapid technological advances and modern expectations. In the USA, the Robotics Industries Association defines a robot as a "reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks". In Japan, classifications are used: M1 are simple tele-operated manipulators; M2A are devices that can be programmed to do fixed repetitions; M2B are those that can perform variable repetitions; M3A are more sophisticated devices that can be taught a sequence of steps by an operator leading them through the motions; M3B are robots that can be numerically controlled with a computer; and, ultimately, M4 are robots having "artificial intelligence" that are capable of fully autonomous operation.

Today the technology generally is considered to be at the M3 stage, with research and development well into the M4 level. Computer "chips", sensors, television cameras, and other electronic devices are fuelling the evolution. Economics, however, will dictate the extent of future applications, experts say.

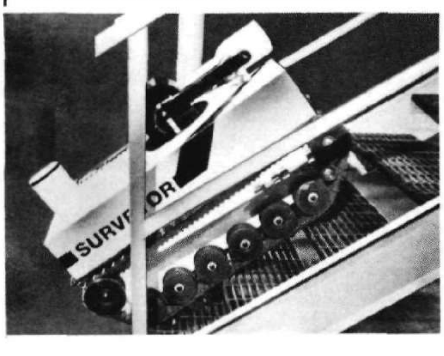
In the nuclear industry, mechanical cranes and manipulators used in the early days of development are among the forerunners of today's more advanced remote systems and robotic technologies. One of the first robots for practical use was developed in 1958 by Hughes Aircraft to handle radioactive materials at nuclear facilities in the USA.

Some indications of how far the technology has come in the nuclear industry emerged at an international seminar last year convened jointly by the IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development. More than 200 participants exchanged information detailing the advances in electronics, optical/visual systems, and material technology that have combined to enable innovations and improvements. (*Proceedings of the Seminar on Remote Handling in Nuclear Facilities* now are available from the OECD, 2 rue André-Pascal, 75775 Paris, Cedex 16, France.)

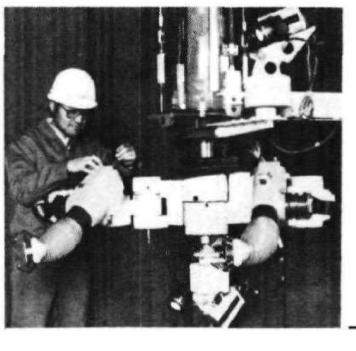
Photos on these pages show some robotic systems in use today.

Information for this article is drawn from "Industrial Robots on the Line", by Robert Ayres and Steve Miller, *Technology Review* (May/June 1982), and from an article by T. Moore in *EPRI Journal* (November 1984).

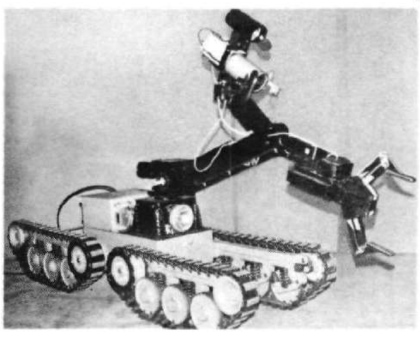
Surveyor can be used to monitor radiation, listen for steam leaks, and read gauges. (Credit: Automation Technologies, Inc.)



A robot manipulator for use in Japan's reprocessing plants and radioactive waste facilities. (Credit: PNC, Japan)



The MF3, developed by CMS Technologies, Inc., in the FRG, has been used at nuclear plants over the past 10 years. (Credit: EPRI)



day stem from the fact that the plants were not built with such devices in mind; advanced reactor plants of the future will likely have special features specifically to accommodate surveillance or maintenance robots.

Under an EPRI contract, Westinghouse's Advanced Energy Systems Division studied the feasibility of using robots in a large-scale prototype breeder reactor. The analysis considered various routine and nonroutine maintenance and inspection tasks and outlined design factors that could enhance the applicability of robots These include provision of adequate work and access areas, lighting and power outlets, and location of equipment and other potential obstructions.

As more special-purpose robots are developed for nuclear applications, the job of technically evaluating these devices with utility requirements in mind will also grow. EPRI's NDE Center may take on expanded responsibilities in this regard, having already participated in the technical evaluation of IRIS.

Breaking new ground

Directed R&D efforts and the immediate needs in nuclear power plants for reduced maintenance costs and lower occupational radiation exposure are breaking new ground in the application of robots to tasks with which most people would rather not be burdened. Despite the significant achievements to date, however, researchers caution that much more progress must be made before robots are seriously considered as reliable, economic tools. The entry of robots into the nation's nuclear plants will not occur rapidly, but a trend in industry thinking toward applying robotic equipment when and where it is feasible is already clear.

Michael Kolar, until recently an EPRI senior program manager who was involved in the Institute's study of robotic applications since the effort began in 1981, reflects the mixed viewpoints among many researchers in the field.

"There is some robotic technology that will let you do certain jobs, but it's not at all clear that you'll see many of these machines in wide use in the near future," says Kolar. "There are significant unresolved uncertainties, relating not only to the technology's hardware and software but also to other issues. Will the time required to train crews and execute a job with robots be short enough to be practical? That's not yet clear. NRC may decide to regulate some aspects of plant maintenance, and the role of robots in licensing issues has not yet been defined.

"Ultimately it will all come down to economics—are robots truly cost-beneficial?" asks Kolar. "Unless the costs of robot systems come down, or someone offers to provide them as part of a service package, I don't think we'll see widespread use of sophisticated robots soon. For EPRI, the issue is to ensure that good technology gets into the plants. But first, we have to find out what these machines can do. If we succeed, robots just might make it."

Utilities are expressing increasing interest in robots for nuclear plant applications, and as a result, the R&D community and the robot industry are responding with a range of devices and machine capabilities The current activity represents a model of cooperative research, with both large and small companies, universities, government, and industry research groups working together to advance the technology. If recent success is any indication of the future, the outlook for robots to make a significant contribution to improved plant economics is encouraging.

For further reading . . .

Evaluation of Robotic Inspection Systems at Nuclear Power Plants, prepared for US Nuclear Regulatory Commission by Remote Technology Corp., NUREG/CR-3717 (March 1984).

Automated Nuclear Plant Maintenance, final report for RP2232-1, prepared by Battelle, Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201 (1985).

"Industrial Remote Inspection System", by E.B. Silverman, *Proceedings of the Robotics and Remote Handling in Hostile Environments, National Topical Meeting,* American Nuclear Society (1984).