Stepping Into Danger

Not all robots work in factories. A few are taking their first, tentative steps into nuclear power plants, mines and construction sites.

By IVARS PETERSON

A mine shaft sunk thousands of feet into the earth can be a hot, dusty, dangerous place to work. A construction site — whether a steel and concrete tower or a claustrophobia-inducing tunnel — presents its own unpredictable hazards. So, too, does a crippled or aging nuclear power plant ready for dismantling. At risk is the well-being of human workers sent in to cope with these conditions.

Coal mining, for instance, despite a greatly improved safety record in recent years, is still one of the most dangerous occupations in the United States. "Safety is not as good as it should be," says mechanical engineer Carl R. Peterson of the Massachusetts Institute of Technology (MIT). "Because we have not been able to remove the hazard from the operator, it's clear we ought to consider removing the operator from the hazard."

One answer, which has become a possibility only in recent years, is to bring in machines operated by remote control or robots that can function independently. What makes this possible now is the rapid improvement in computers, sensors and automatic control.

This doesn't mean that humanlike robots are likely to be hammering nails, operating drills or crawling through narrow passageways. Instead, machines will be designed for specific tasks. In some cases, mining and construction practices may be altered to take better advantage of what machines do best.

"The popular-science concept of putting in a robot to do exactly what a human used to do is unlikely," says Peterson. "The idea is to design the capabilities of these high-tech things for what machines can do."

Because a factory's environment is largely controlled, robots already play an important role in manufacturing. In mining or construction, however, robots would have to deal with working conditions that often change.

"The biggest single difficulty . . . is that the environment is unpredictable," says Peterson. "No matter how harsh an environment is, it's a great deal easier to handle if it's predictable."

"In general," says robotics researcher Irving J. Oppenheim of Carnegie-Mellon University in Pittsburgh, "construction robots will require the most advanced capabilities in terms of intelligence and sensing to work autonomously in an uncontrolled environment.

"It [the robot] has to be able to move around things that weren't there 20 minutes ago," he says. "It has to be able to navigate itself. It requires an intelligence, which is not needed in most manufacturing applications."

Japanese builders are interested in robots because the productivity of Japan's construction industry has not improved significantly for decades, says Seishi Suzuki of the Shimizu Construction Co. in Tokyo. Meanwhile, robots and other forms of automation have greatly increased manufacturing productivity.

Moreover, the high accident rate of construction work combined with the shortage of Japanese construction workers makes robotics technology an attractive solution, says Suzuki.

A variety of special but relatively simple robots are now being tested at construction sites in Japan. They are being used to spray fireproofing or insulating materials onto ceilings and walls and for finishing floors after concrete has been poured. Others help position steel beams so that they can be bolted together, or carry and place long, heavy steel rods for reinforced concrete slabs. On some sites, suspended "wall crawlers" inspect the quality of work done.

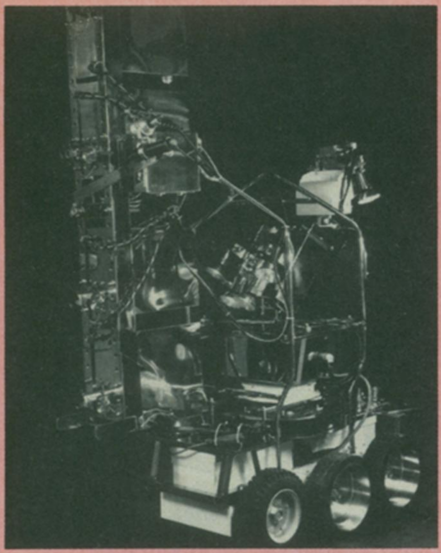
So far, these experimental robots are not particularly independent or flexible, says Suzuki. "The development of construction robots in Japan has just begun," he says. "There are many difficulties, but a great number of opportunities as well."

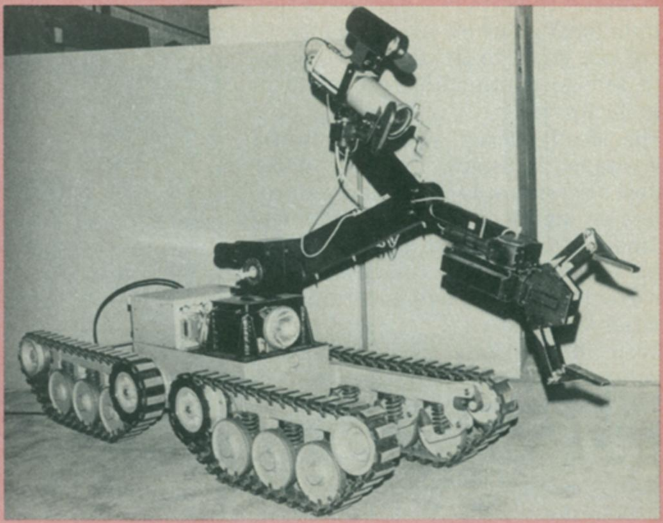
The Japanese government is also promoting a national program to develop advanced robots for dismantling obsolete nuclear power plants, for handling or cleaning up hazardous wastes, for underwater applications and for rescue and other uses in disasters such as fires.

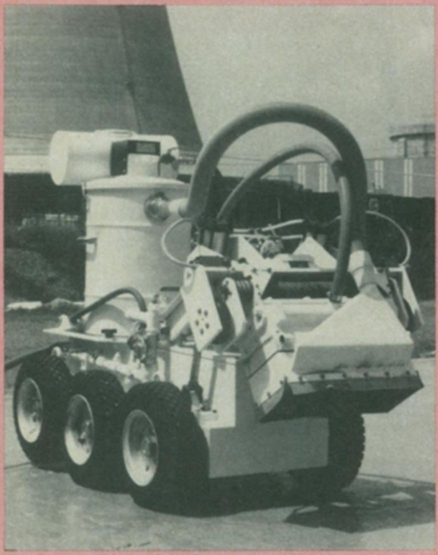
Much of Japan's robotics development has involved modifying currently available machines by adding computers and sensors rather than fundamentally redesigning the machinery. In contrast, research in the United States has tended to focus on long-term capabilities rather than on immediate applications, says Oppenheim. This includes work on vehicles that can navigate themselves using vision or acoustic sensors and on computer programs and expert systems that will eventually guide these robots.

At Carnegie-Mellon, William L. Whittaker and his colleagues are developing an experimental robotic excavator (REX), which is designed to unearth buried utility pipelines. REX uses sonar to map an excavation site and guide its digging operations. Its supersonic air-jet cutter dislodges dirt and sand.

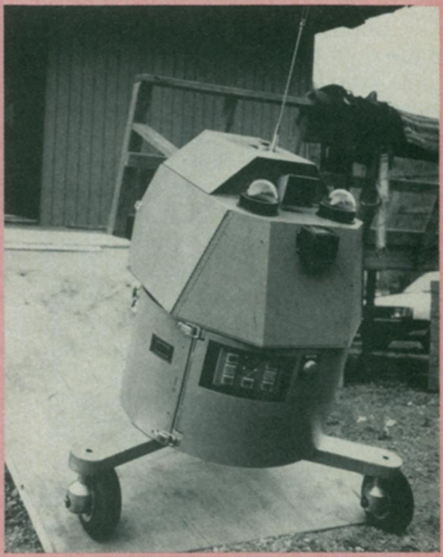
In a test last year, a prototype excavator was able to find and dig out pipes buried in a laboratory pit. A later field test was also successful. These experiments suggested several improvements, including a new magnetic mapping system and a better cutter. "Instead of an arm that just goes to locations on the acoustic map," says Whittaker, "we are incorporating force feedback so that we are able not just







A variety of robots are being tested or used in nuclear power plants. Carnegie-Mellon University's Remote Reconnaissance Vehicle (top left) has ventured into the radioactive containment building at Three Mile Island. The MF3 (top right) has been in use for 10 years in West Germany for plant maintenance. The Moose (bottom left) is designed to break up contaminated concrete. Kluge (bottom right) can squeeze through extremely narrow passageways.



Mary Jo Dowling/CMU (top left); EPRI (all others)

to sweep passively over the soil but rather to dig into it."

Eventually, an advanced version of this robotic excavator should be able to excavate around leaking gas lines—work considered extremely hazardous for humans. This technology may also be extended to applications like unmanned sandblasting, spray washing or surface soil removal.

Terregator, another Carnegie-Mellon research robot, is a driverless, outdoor vehicle used in autonomous navigation research. Vision navigation experiments, using a single video camera at first and then a stereo vision system, have taken this machine along campus sidewalks, parks and roads. Using acoustic range sensors, it has also successfully navigated a portion of a local coal mine.

More recently, Terregator used a laser ranging device that scans a scene to give the robot a sense of depth. "It's somewhat like looking into a monochrome video image," says Whittaker, "but rather than the light and dark being illumination contrasts, they correspond to depths measured in the scene." In this way, a mobile, laser-equipped robot can pick out, say, trees or buildings by detecting abrupt changes in depth. The technique worked very well in a recent coal mine test.

"Our real demonstration piece will be the circumnavigation of a local park using all the capabilities," says Whittaker. "The idea there is, say, to travel along a trail for a while until you come to a cluster of trees, then head out cross-country, on the lookout for another path, to find it . . . and then travel on. That's our ideal or goal."

Robots can also be designed to inspect pipelines from within. Such a machine would travel underground, using vision and pressure sensors to inspect concrete pipes. It could also make repairs by, for example, packing weak spots with epoxy.

Another possibility is a robot bridge inspector equipped with magnetic feet so that it can creep along a bridge's framework. "There's no reason why you can't develop an automated piece of machinery custom-made for a specific bridge," says Rolland B. Guy, who heads a construction automation study for the Battelle Columbus (Ohio) Laboratories. "It would continuously monitor the quality of the bridge and maybe even maintain it." Such machines would be able to do more frequent and more thorough inspections than human inspectors, and human workers could be removed from hazardous jobs like painting.

However, the U.S. construction industry has shown little interest in new technologies. "When it comes to innovation, we in the U.S. construction industry are behind the rest of the world in automation on the construction site," says Guy. "Either that's going to have to change, or we're not going to be able to compete with foreign contractors or equipment manufacturers."

The steady decay of U.S. highways, mass-transit systems, ports, water mains, sewers and bridges may yet provide a strong incentive to develop new technologies. The cost of this repair effort could amount to as much as $1 trillion over the next 20 years, according to a number of estimates.

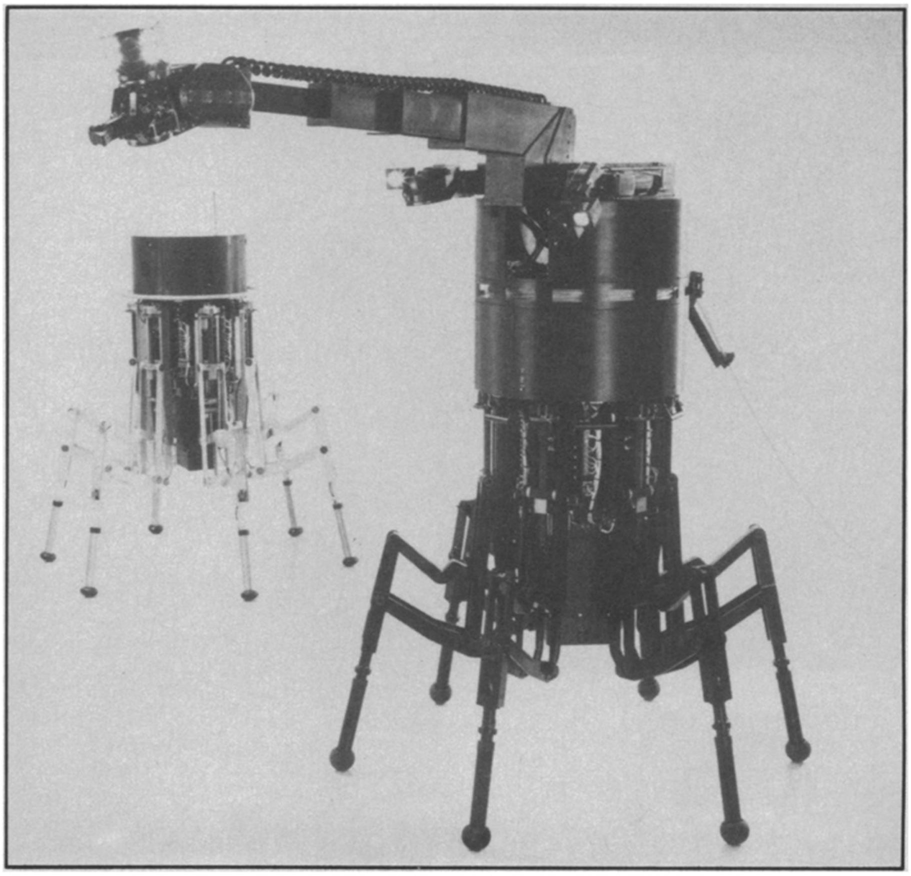
Even if remotely controlled and robotic devices are expensive to develop, they would pay for themselves many times over, some engineers claim. This would be especially relevant for jobs in inaccessible or hazardous locations or work that has to be done at inconvenient times for human workers.

The nuclear power industry is already taking a serious look at robotics. But limited capabilities and the high cost of currently available models are restricting the introduction of robot workers to a few special situations.

The Electric Power Research Institute (EPRI), a utilities-sponsored research organization based in Palo Alto, Calif., is now studying a variety of robots that may become part of the nuclear industry's work force. EPRI's main goal in robotics research is to place machines in nuclear power plant environments that have dangerous levels of ionizing radiation, extreme heat or noxious fumes—conditions that hinder human activity. Such robots would be used mainly for surveillance or maintenance.

Kluge, for example, developed by Cybermation Inc. of Roanoke, Va., is a radio-controlled, three-wheeled machine that can navigate extremely narrow passageways. The inspection robot "Surveyor," produced by the Automation Technology Corp. in Columbia, Md., can churn through water up to 6 inches deep and maneuver through openings only 32 inches tall (SN:3/29/86,p.203). The Moose, on the other hand, can deliver up to 1,200 hammer blows per minute when breaking up a contaminated reactor building's radioactive concrete floors. This mobile robot was designed by Pentek, Inc., in Coraopolis, Pa.

Remotely controlled vehicles, developed in West Germany, may be used by the Soviet Union to assess damage at the Chernobyl nuclear power plant (SN: 5/3/86,p.276). These radio-controlled "MF2" robots are about the size of a small car and carry television cameras and radiation sampling equipment. West Germany has been using maintenance robots in nuclear power plants for nearly a decade and includes special robots in its task force for handling nuclear plant emergencies.



Odetics

The Savannah River Laboratory Walking Robot (right) is specially designed to operate in a nuclear facility. This new robot is an advanced version of the ODEX-I walking robot (left), first demonstrated in 1983. It can lift as much as 300 pounds and step as high as 30 inches. Its manipulator arm can be extended 6 feet.

Two robots specially designed at Carnegie-Mellon University have already ventured into the mud-covered, radioactive basement of the damaged Three Mile Island (TMI) Unit 2 nuclear power plant. Radiation levels there are still up to 500 times higher than the safety limit for human exposure.

The first "Remote Reconnaissance Vehicle," nicknamed Rover 1, took video pictures of floors, walls and equipment and measured radiation levels at various points in the structure. Late last year, Rover 2 took samples from the containment building's inside walls to see how deeply radiation had penetrated. A third "Workhorse" robot, just completed and soon to be delivered to TMI, has a 23-foot arm that can hold and manipulate a variety of cleanup tools, from wrenches and saws to hoses and scrapers. Overall, the TMI cleanup will require about half a dozen different robots.

"No one wanted to touch this kind of thing when we first started," says Whittaker. "But now attitudes are changing." People are beginning to look more closely into whether remotely operated or autonomous work vehicles may be cost-effective for construction and other field applications as well. "There are a lot of people coming on board," he says, especially in Japan and Europe.

The problem of bringing a robot into the world outside a factory involves more than making the robot mobile and equipping it with the right kinds of sensors. It must be rugged and, for many applications, powerful. And its sensitive equipment must be protected from radiation, dust, mud, heat, stray electrical signals and numerous other hazards.

In mining, roof collapse is a constant danger. This puts constraints not only on human activity but also on the types of machines that can be used. A typical mining robot of the future would probably be some kind of armored, tracked vehicle designed for specific jobs like drilling holes or cutting away layers of rock. Just adding computers and sensors to current machines would not be enough.

"If there is a major change in coal-mining practice, it will be a shift to remote control," says Peterson. "But present systems are far too complex to be run by remote control. The existing technology has gone about as far as it can. There are no quick, easy fixes left."

The answer, he says, is to take a fresh look at how mining is done. This means reevaluating tasks now performed by people using conventional machinery and designing robots specifically for those tasks. That may involve changing long-established mining methods to take

Mary Jo Dowling/CMU

Carnegie-Mellon's Terregator is an outdoor vehicle used in navigation research.

better advantage of machine capabilities. However, most of this innovative research is occurring outside of the United States, in countries like West Germany, France, Japan and Canada.

"In many respects, the U.S. minerals industry is in the same relative position as that of the U.S. manufacturing industry a few years ago," says George S. Ansell, president of the Colorado School of Mines (CSM) in Golden. New technologies, including robotics, helped save some of these industries, he says. "The same can and must occur in the minerals industry."

Key questions, Ansell suggests, include: "If we were to reinvent mining, how would we do it?" and "How would we produce minerals safely and efficiently in a worker-free mine?"

To help answer such questions, CSM recently formed the Center for Advanced Mining Systems, which will delve into areas like the application of artificial intelligence techniques for mineral production, systems for sensing in three dimensions, and technologies for extracting minerals when people aren't present to supervise a driller or a cutter.

This year, the American Society of Mechanical Engineers has created the Innovative Excavation Equipment and Systems Institute, based in Washington, D.C. The institute, which is just getting started, comprises several universities, including MIT, the University of California at Berkeley and Pennsylvania State University, and representatives from the mining industry.

"This institute has been created to provide the broadly based, collaborative effort needed to properly explore innovative mining and excavation systems," says Peterson. "Historically, there has been no such mechanism for sustained coordination, and the better [mining] systems called for simply cannot be developed by individual contributors."

The institute may make it easier to bring in experts like civil engineers who are involved in building tunnels or digging shafts for deep missile silos or military facilities. This kind of information could help mining engineers. Surprisingly, says Peterson, very little such interaction has occurred in the past.

Construction of the first underground nuclear waste repository may also provide some useful opportunities. "One of the things that the mining research community has always needed but never had," says Peterson, "is a research mine. Finding a place for a field test is extremely difficult." The test shafts now being excavated in several states and in several different types of rock would make ideal mining research facilities.

"Mining is not one of the most technologically advanced industries," says Stanley C. Suboleski of the A.T. Massey Coal Co. in Richmond, Va. But increased productivity isn't necessarily the main or only reason for considering the introduction of greater automation and robots. "Inherently, mining is always going to be a little more dangerous than working on the surface," says Suboleski. "The mine that we would like to see is a mine without any people in it." If that can't be done, he says, then mining technology should be developed to get people away from the working face, where drilling or cutting is taking place.

Hazard has pushed much of the work in robotics, says Whittaker. "I look for problems where you see people taped up in suits," he says. "I look for problems where there's no choice. You have to do something. That's a good place to start." Whether in mines, construction sites or nuclear power plants, robots can go where humans fear to tread. □