Remote-controlled equipment for decommissioning

Improved robots and manipulators offer practical advantages

For some decades now, automation and robots have been used with success in various forms for industrial handling, assembly, and manipulation jobs. In the nuclear industry, a wide range of specialized manipulators and equipment have been, and continue to be, developed to perform remote tasks such as inspection, maintenance, repair, and refurbishment.

The use of such devices is one important way of reducing human exposure to radiation during decommissioning and decontamination operations at nuclear facilities. Consequently, decommissioning costs also may be reduced.

What is meant by the terms "robot" and "manipulator"?

Within the context described here, a robot is a programmable handling machine that has a memory, can be trained, and can be retrained easily when changed to a new job. This latter capability is the characteristic difference between robots and other pieces of automated equipment, although the flexibility of numerically controlled equipment is also high. Robots basically consist of mechanical components, actuators, controls, and sensors, and generally have many degrees of freedom.

A manipulator, on the other hand, has many features of a robot, but it is usually operated directly under some form of manual control, which may be remote. Programmed control of a manipulator can be accomplished (producing a form of robot), just as manual control of a robot is possible through an appropriate control system.

For decommissioning and decontamination work, the following components are important for both robot and manipulator applications:

- Task analysis
- Remote control technology
- Advanced mechanical engineering
- Simulation technology
- Remote sensing equipment
- Man-machine interface.

Programmes in the nuclear industry

In the nuclear industry, remotely operated equipment has been used for handling, inspection, dismantling, assembly, repair, replacement, and fabrication tasks in reactors, shielded cell facilities, underwater bays, reprocessing plants, fuel fabrication plants, and radioisotope production facilities, for example.

Of most interest from a decommissioning viewpoint are the remotely operated manipulators, robots (stationary and mobile), the visual and sensor technology, and the computer hardware and software associated with the equipment.

The types of manipulators in use include relatively simple master/slave manipulators, sophisticated bilateral force-reflecting electric manipulators (in which the master and slave can be connected by direct wire, radio, or laser beam) and the most advanced and dexterous computer-aided master/slave servomanipulators. In addition, industrial manipulators can be equipped with environmentally conditioned and shielded cab enclosures and mounted on vehicles if necessary.

Automatically guided vehicle systems have been used in industry for many years for a variety of tasks. Some are free-ranging with optical or radio-controlled guidance systems while others follow guidance wires installed under the floor. Specialized track and wheel vehicles have been developed for the nuclear industry as well. For decommissioning, such vehicles may be used as mobile bases for carrying manipulator arms and equipment to do work in areas having high radiation fields. A study detailing the options for decommissioning has been completed for the Commission of the European Communities (CEC).*

These general purpose mobile robots can advantageously replace man for multiple tasks such as surveying and monitoring. Physical measurements are possible (for example, of radiation levels, temperature, humidity) as well as scabbling and decontaminating walls and floors. The load capacity of the vehicle-borne manipulators determines the extent to which small compacts can be disassembled and other tasks, such as building shielding walls, can be achieved.

The remote technique can be extended to larger vehicles such as bulldozers, backhoes, and excavators required for mass concrete demolition. Radio-controlled systems that operate control levers on these machines are commercially available.

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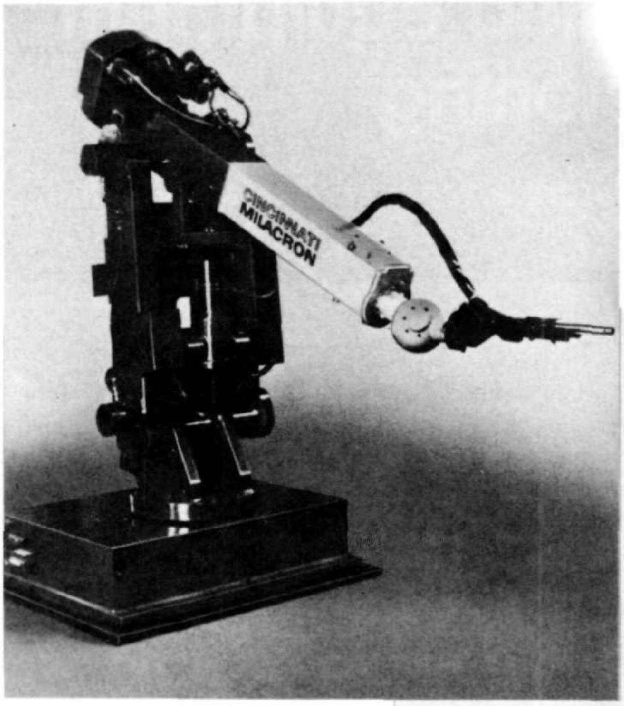
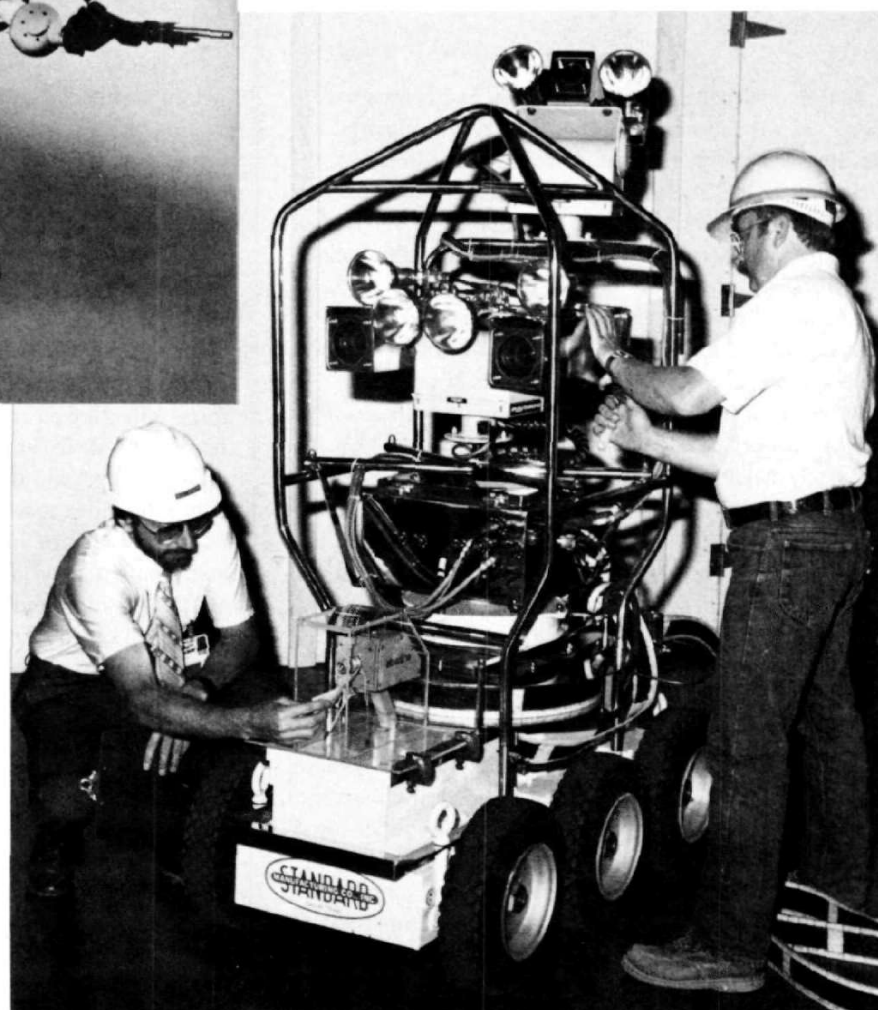
* See "Review of Systems for Remotely Controlled Decommissioning Operations", by L. Da Costa et al., Commission of the European Communities (in press 1985).



Robotic arm for use in decommissioning activities. (Credit: *Cincinnati Milacron*)



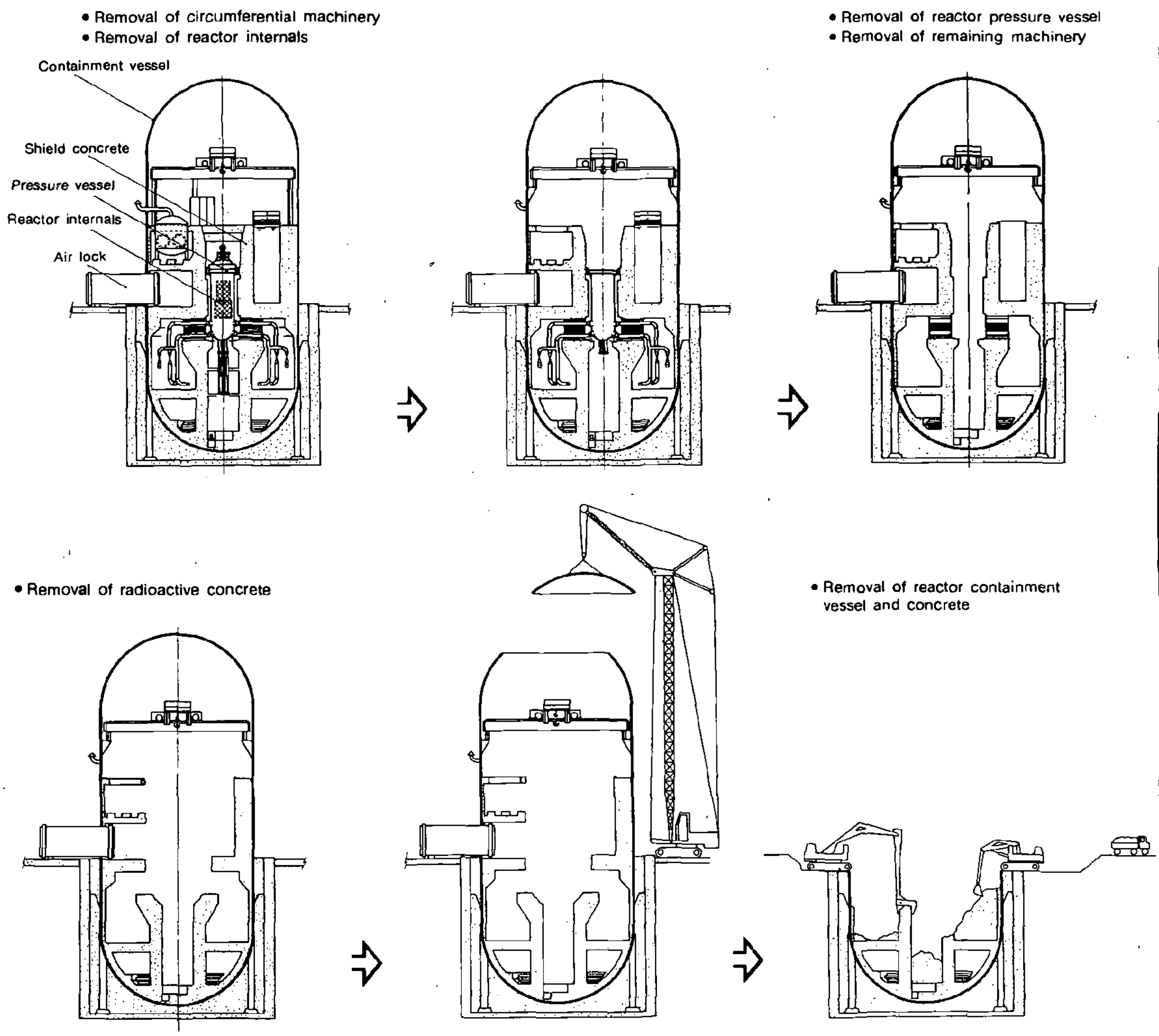
At TMI-2, workers check "Rover", a robot that made the first extensive post-accident examination of the reactor building basement. (Credit: GPU Nuclear)

For underwater use, manipulators mounted on submersibles are available, and similar ones can be envisaged for underwater nuclear decommissioning applications. However, this would require significant development.

In France, a sophisticated servomanipulator equipped with television and telescopic supports with computer control has been developed and is being used for remote maintenance and decommissioning tasks. The combination of options permits the arm to be operated either as a manually controlled maintenance manipulator or as a computer-controlled robot.

In Canada, a sophisticated remote manipulator subsystem (RMS) is being developed by SPAR Aerospace for Ontario Hydro for possible use in the retubing of Pickering reactors. It uses technology developed by SPAR for the arm used on the US space shuttle vehicles. The RMS is one part of a co-ordinated Remote Manipulator and Control System that will be used for a variety of handling, inspection, support, and transport activities, as well as maneuvering containers in the fuelling machine vault. In another project, Atomic Energy of Canada Limited has developed a complex remotely controlled arm with a viewing system and a remote welding machine to repair leaking pipes located in a vault below the Douglas Point nuclear reactor.

In Japan, a comprehensive programme is in progress to develop a robotic remote handling system for the decommissioning of the 90 megawatt (thermal) power



In Japan, the first reactor to have generated electricity will also be the first one decommissioned. Called the JPDR (for Japanese power demonstration reactor), the plant began operations in 1963, was shut down in 1976, and now is scheduled to be dismantled by the end of this decade. The diagram shows the tentative procedure envisioned for taking apart the boiling-water reactor. The decommissioning project is being conducted by the Japan Atomic Energy Research Institute (JAERI). (Credit: *Science & Technology in Japan*, Vol.4, No.16, Three "I" Publications, Ltd.)

demonstration reactor (JPDR). During the first part of the study, emphasis is being placed on the development of man-machine interfaces and advanced control systems to improve ease of operation, flexibility, dexterity, and autonomy. Features such as semi-automatic trajectory control and collision avoidance for vehicle and manipulator will be developed. Based on this work, light- and heavy-duty remote handling systems equipped with underwater power manipulators capable of handling 10 and 100 kilograms, respectively, will be available by the end of 1986.

In the United Kingdom, the Atomic Energy Authority is developing sophisticated remotely operated equipment for the decommissioning of the 33-megawatt Windscale advanced gas-cooled reactor (WAGR), scheduled for completion by 1994. In concept, the decommissioning machine system consists of a shielded gantry supporting an extendable rigid mast, and an elevating platform holding a remotely operated manipulator that will be used to perform the dexterous activities associated with dismantling. Remotely operated plasma-arc cutting and stereo TV systems are being investigated for use with the decommissioning machine in dismantling the reactor and removing the waste.

In the Federal Republic of Germany, similar automated or remotely operated dismantling and handling equipment is being developed for the decommissioning of the 100-megawatt Niederaichbach (KKN) gas-cooled pressure tube reactor. The reactor will be dismantled, segmented, and packaged by remote operation using a rotary manipulator, a cutting manipulator, and a crane manipulator.

The principles developed at WAGR and KKN can be applied to the design of manipulators for use in the decommissioning of other pressure vessels.

Criteria for remote operations equipment

The use of remotely operated equipment in the nuclear industry implies that it will be operated in a hostile environment in which it may get contaminated. Also, human access to the equipment for adjustments, repairs and/or replacement is often difficult or hazardous and cannot be done until the unit has been decontaminated.

In designing or selecting remotely operated equipment for use in decommissioning tasks, the performance of the equipment should be carefully considered. Criteria that should be followed wherever possible include:

- Performance of the machine even under fault conditions must be fail safe.
- The machine must be reliable, durable, and able to complete the appointed task.
- Human access to the machine, although often restricted, must be sufficient for deployment, operation, and retrieval. The machine design should also enable easy maintenance, repair, and dismantling.
- When used in contaminated conditions, the machine must be designed to allow easy decontamination.
- The life-cycle cost should be calculated to include decontamination and/or disposal of the machine.
- The man-machine interface must be considered in the control of the machine to ensure that the operator's performance is not impaired.
- The machine should be extensively tested in mock-up facilities before it is committed to the actual task.
- Connectors and fasteners should be designed for operation under remote conditions when necessary.
- Components should be radiation tolerant; controls and as many other components as possible should be designed to remain separate from, and outside of, the active zone.
- The operational environmental conditions (such as temperature, pressure, humidity, dust, chemical activity) should be considered in the design.
- Where practical, available and proven industrial components and/or units should be used, even if minor modification is required.
- The design should be as simple as possible, but still achieve the foregoing criteria.

Industrial robots: Various types for multiple uses

The kinematic functions of industrial robots usually are evaluated by comparison with the original "multipurpose manipulator" — the human arm and hand — and most robots are designed to try and duplicate man's capabilities. Many have an articulated mechanical arm onto which various devices such as a gripper, grinder, paint sprayer, welding gun, or pneumatic wrench can be attached. The design and operation of these devices (called "end-effectors") — which take the place of the human hand — are as important as the design of the robotic arm itself.

The human arm and wrist — in addition to spatial control — can re-orient an object through three planes of rotation giving a total of six degrees of freedom (three translational axes and three rotational axes). The human hand itself has 22 separate movements. When combined with human sensory functions, the feedback system, and the ability of the human brain to automatically select the sensory feedback most appropriate to every moment, the human arm is a very versatile and complex mechanism. It is also very strong (a strength to weight ratio of about 5) and lightweight.

To simulate the spatial and re-orientation functions of the human arm and wrist, a robotic arm or manipulator must have at least six degrees of freedom. Often as many as eight or nine degrees of freedom are used to permit the robotic arms to reach around obstacles. In most cases, the 22 movements of the human hand are replaced with a simple pincer device, although in very special cases anthromorphic hands with articulated and powered fingers have been developed.

The actuators of a robot can be operated pneumatically, hydraulically, electrically, mechanically or in some combination of the four basic drives.

The most difficult task in developing a robotic arm is to simulate the control functions of the human arm. The development of specialized computers, processors, and memories has ushered in a new phase for robotic control. The designer can increase the intelligence of the robot by using mathematical equations for complex motions and more complicated sensory devices.

The design of the robots and control systems currently in use vary widely and range from simple limited-sequence robots to sophisticated computer-controlled robots.

Many thousands of limited-sequence robots — mainly of the "pick and place" type — are being used successfully in factories throughout the world. These robots only require a limited number of sequential actions to do their job and do not require the control of motion of more sophisticated robots. Each step of the operations sequence is pre-programmed and controlled by an electric or pneumatic signal from a plugboard control panel. Mechanical stops are generally used to limit the motion of each joint. Although most devices have no ability to get feedback from their working environment, some have been combined with other devices to permit some intelligence. The technology associated with limited sequence robots would not appear to have much application in decommissioning and decontamination work, since the robots are relatively difficult to re-program.

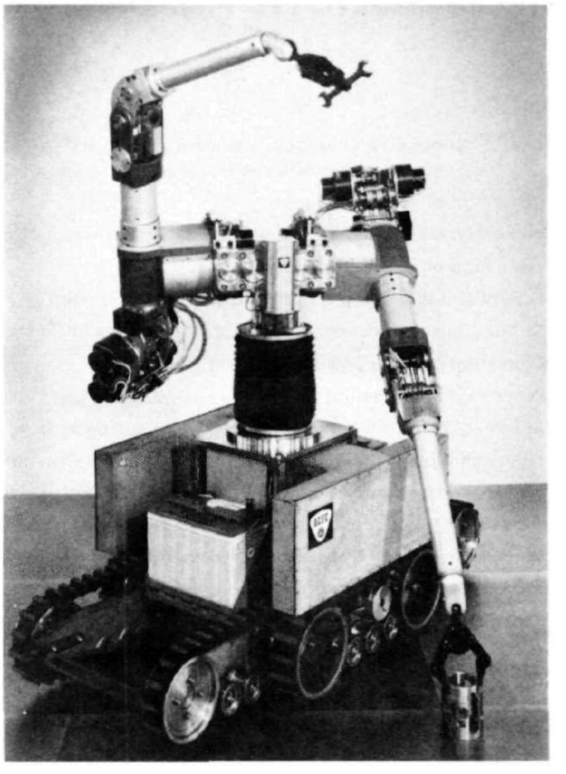
In more sophisticated commercial robots, one of the most important components is the control system which dictates when and how the robotic hardware will perform its tasks. The control system, which consists of a computer, a high capacity memory and sensory feedback, must have simple and fast on- and off-line programming abilities. Additionally, it must be capable of interacting with an operator and with feedback from as many sensors as are required to do the job. Sensors permit the measurement of the system's state in real time and can provide feedback to the controls. Typical ones are laser range finders, television systems, tactile, force, torque, and proximity sensors. Computers store input data and complex programs for the robot, compare the measured and desired performance, generate complex sequences of desired outputs and permit communication between a human and the complex robot.

Software technology

Just as important as the robotic hardware and controls is the new software technology being developed. For example, interactive computer graphics systems could permit the automation engineer to put the robotically operated equipment through its paces on a computer screen rather than through "trial and error" in a highly radioactive environment. This means that the engineer can feed into the graphics computer the design and location of the piping, equipment, and the surrounding facility, for example. The robot and its working tool also can be pre-programmed before installation.

For example, if a series of pipes of various sizes and shapes have to be cut, a robot mounted on a mobile remote-controlled vehicle, a crane, or a gantry, and having a cutting torch as an end-effector could be pre-programmed to cut through the pipes in the right sequence. Collision avoidance should be achieved by using sensors or the software model of the environment derived from the graphics system. This type of technology would appear to be well worth developing for decommissioning and decontamination, as well as for maintenance, using either sophisticated robots or more conventional kinds of remote system technology combined with various tools.

Advanced robotic systems, which are being used in a wide range of factories for welding, foundry applications, spray painting, delicate assembly jobs, etc., will relieve many workers of dangerous and unpleasant tasks. Direct application of specific industrial robotic systems to decontamination and decommissioning tasks in the nuclear industry depends on activity and contamination levels. However, application of the technology, components and specific robots is feasible and desirable for many tasks. It must be kept in mind that robots having force, touch, and visual sensory capability are available but are still under development; even modest maintenance tasks challenge current robotic technology.



Using its "arms and hands" this robotic system can grip tools and pick up small objects. (Credit: ACEC)

Robotic systems work best when the co-ordinates of the physical environment surrounding them are well defined and within the robot's memory. Continued investment in artificial intelligence research and development and the establishment of interface standards which are common to all robot suppliers will increase the flexibility of future robot applications.

In evaluating the financial attractiveness of applying robotic technology to any activity, conventional return-on-investment and payback calculation methods should not be applied. In addition to the standard savings of the salaries of workers displaced by the robotic system, other savings include the cost of items such as health insurance, less supervision, no parking space, less training, heat, light and power, no pension, sick leave, or man-rem costs, etc. A cost/benefit analysis technique has been established to allow comparison of the cost of robotic applications to nuclear facility inspection.